The "Shoulder" and the "Ridge" in PHENIX:

Medium Response to Fast Partons in Heavy Ion Collisions via Di-hadron Correlations

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for the PHENIX Collaboration

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PH✳ENIX
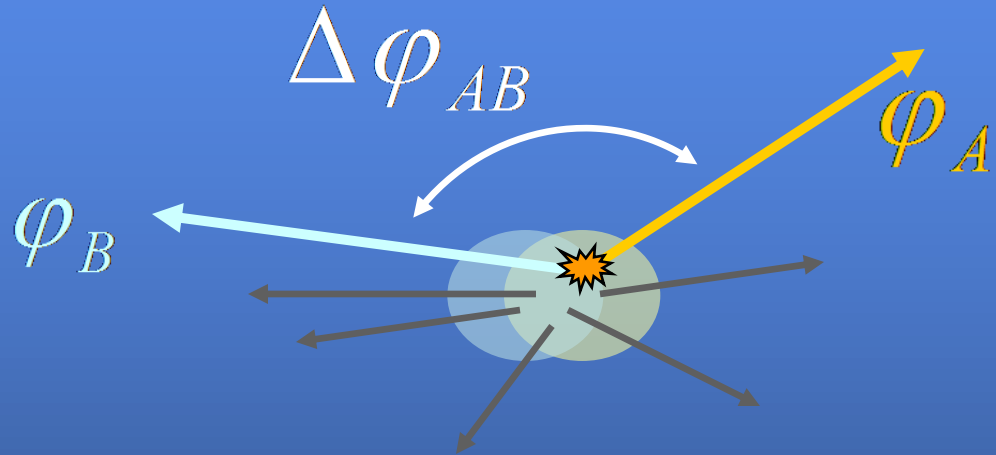
Heavy Ion Collisions

Jet Suppression:

- Fast partons lose energy in the medium

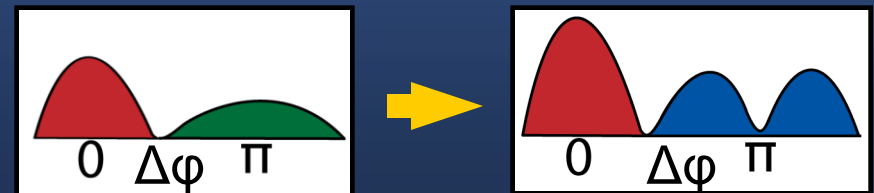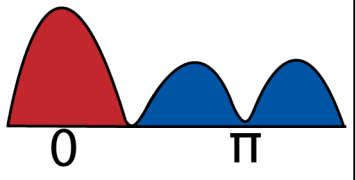- Lost energy should be deposited locally in the medium

  Where does the energy go?

▶ Does anything of the jets remain?

▶ Does the lost jet energy elicit a response from the medium?

Two Particle Correlations:

$$\Delta \varphi_{AB}$$

$$\varphi_A$$

$$\varphi_B$$

- Jet reconstruction difficult in heavy ion collisions

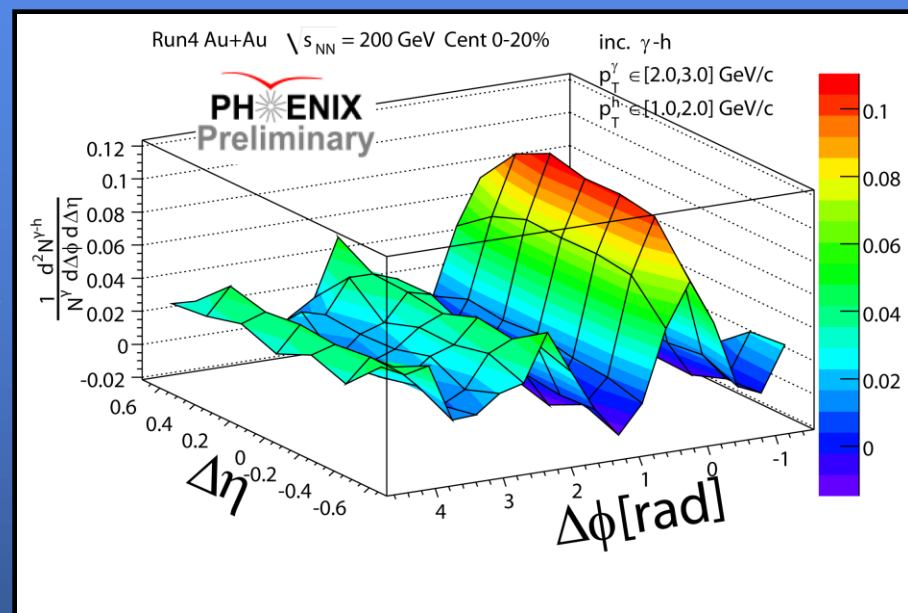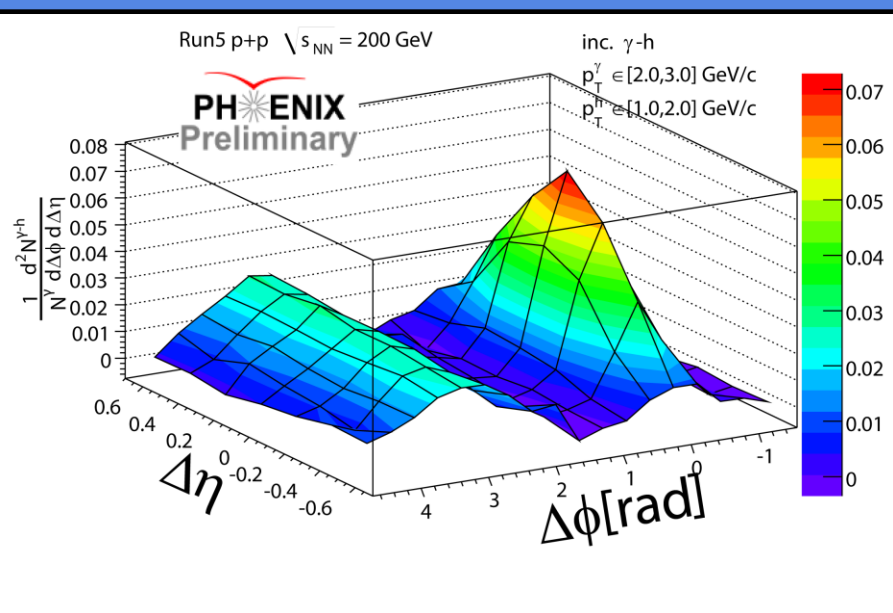- Jet physics can still be studied via two-particle correlations

Medium Response

p+p, peripheral Au+Au

central Au+Au
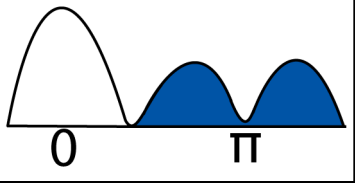

PHENIX poster (Chin-Hao Chen)
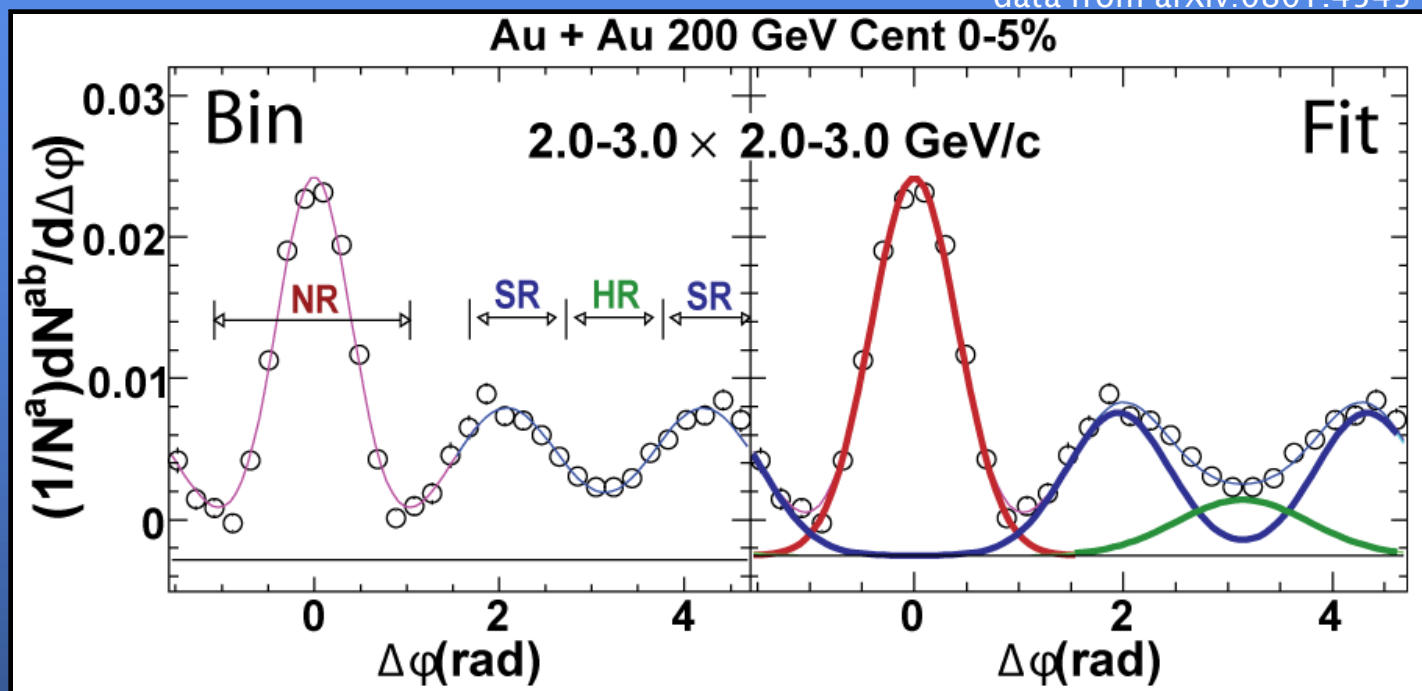
Typical:
- Near-side Jet
- Away-side Jet – "Head"

New:
- Near-side Modification – "Ridge"
- Away-side Modification – "Shoulder"

Near-side Ridge theories: Boosted Excess, Backsplash, Local Heating,…
Away-side Shoulder theories: Mach, Jet Survival + Recom, Scattering,…
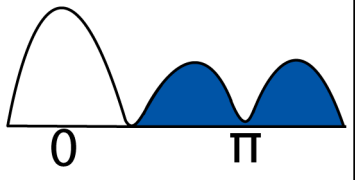
Away-Side Decomposition

Bin Method:
- Model independent
- Measures physics of dominant contribution
- Contamination

Fit Method:
- Model dependent
- Needs higher statistics
- Less contamination
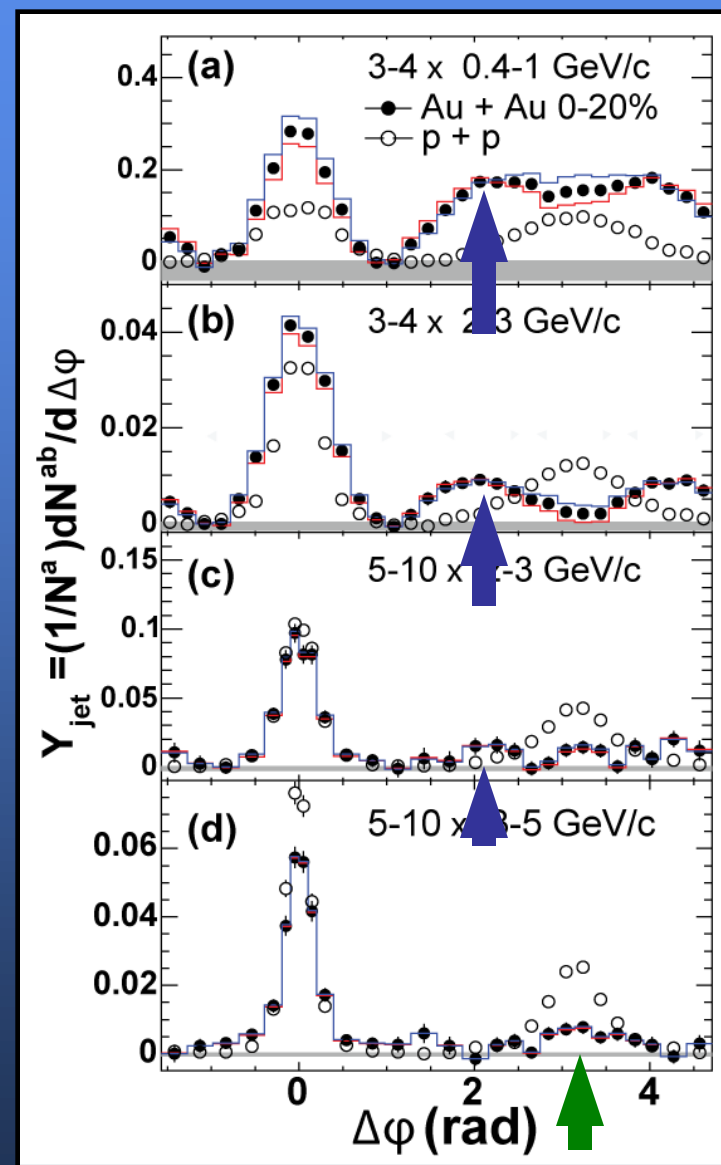
Away-side Contributions

Away-side Head:
- Suppressed relative to p-p baseline

- Dominated by shoulder at low pT
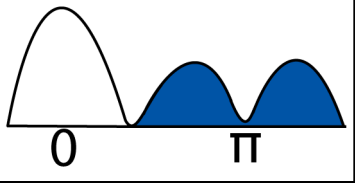
- See Hua Pei's talk in Section IX

Away-side Shoulder:
- Strongest at lower p_T (< 4 GeV/c)

- $\Delta\varphi$ position largely independent of p_T (~ $\pi \pm 1.1$)

increasing p_T

(a) 3-4 x 0.4-1 GeV/c
● Au + Au 0-20%
○ p + p

(b) 3-4 x 2-3 GeV/c

(c) 5-10 x 2-3 GeV/c

(d) 5-10 x 3-5 GeV/c

$Y_{jet} = (1/N^a)dN^{ab}/d\Delta\varphi$
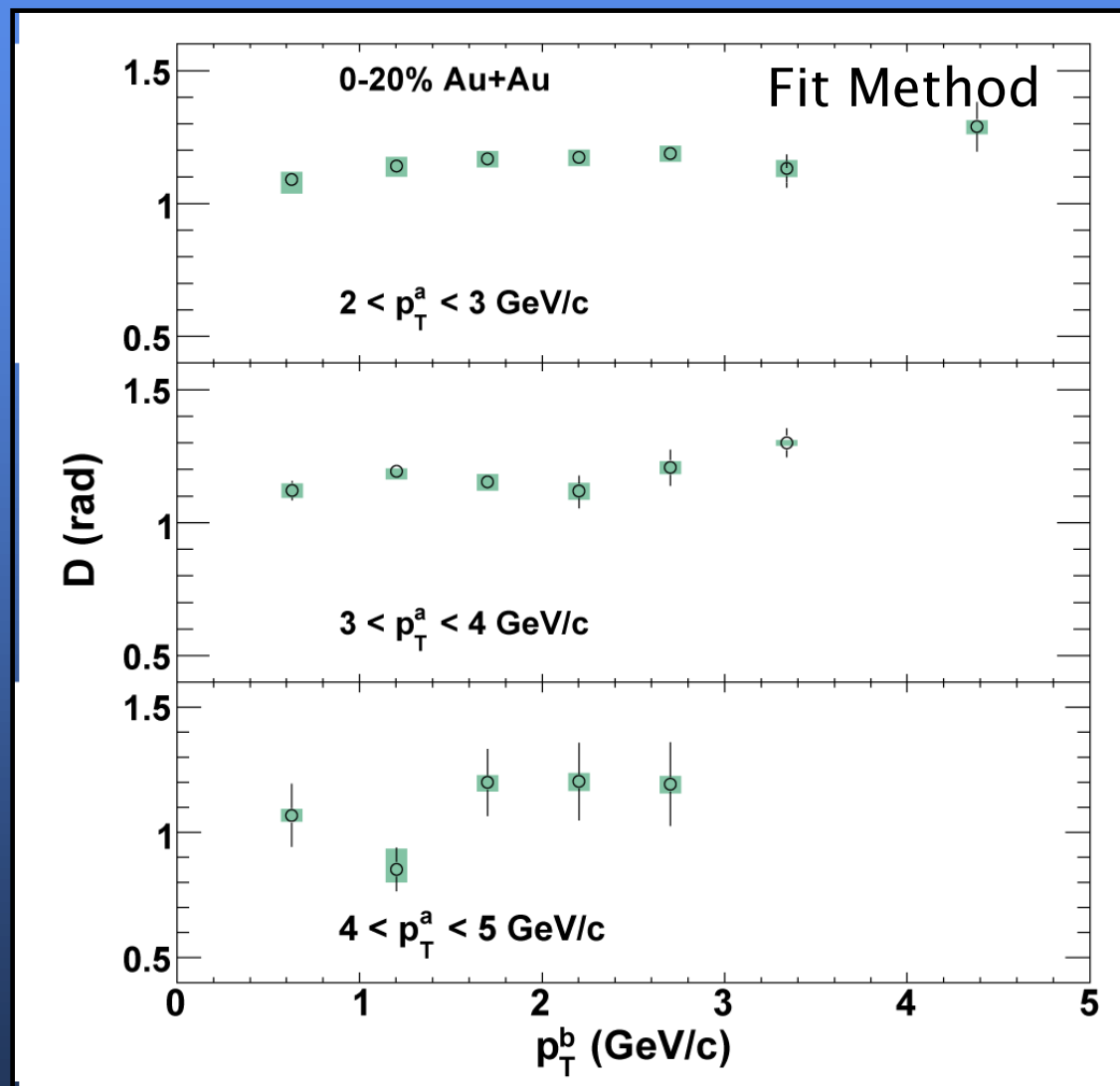
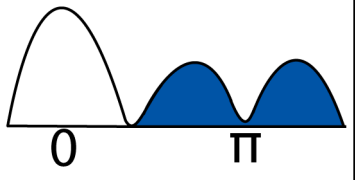$\Delta\varphi$ (rad)

arXiv:0801.4545

Away-side Shoulder Position

- Head region fitted separately

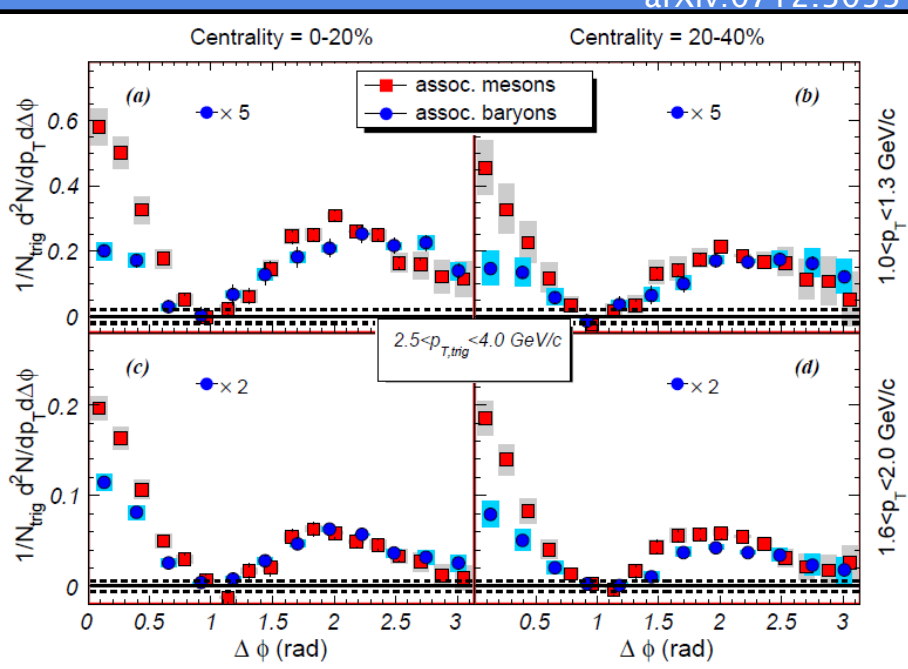- Position largely independent of both trigger and partner p_T selection

arXiv:0801.4545
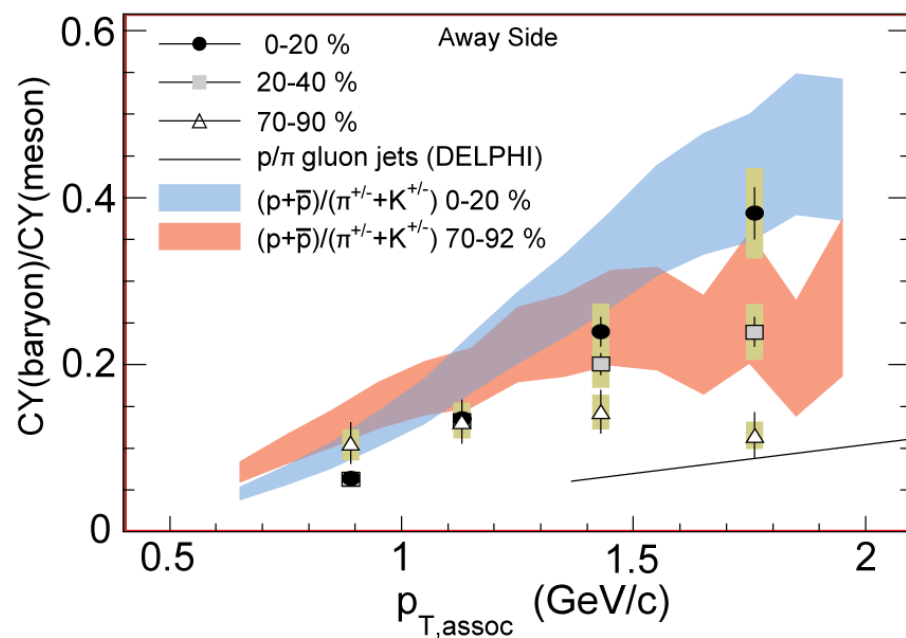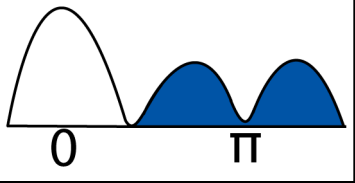
Away-side Composition

arXiv:0712.3033

Ratios:
- Away-side baryon/meson ratios approach inclusive values

- Incompatible with in-vacuum fragmentation

arXiv:0712.3033

Shapes:
- Similar shape in away-side mesons and baryons

Away-side Shoulder Spectra
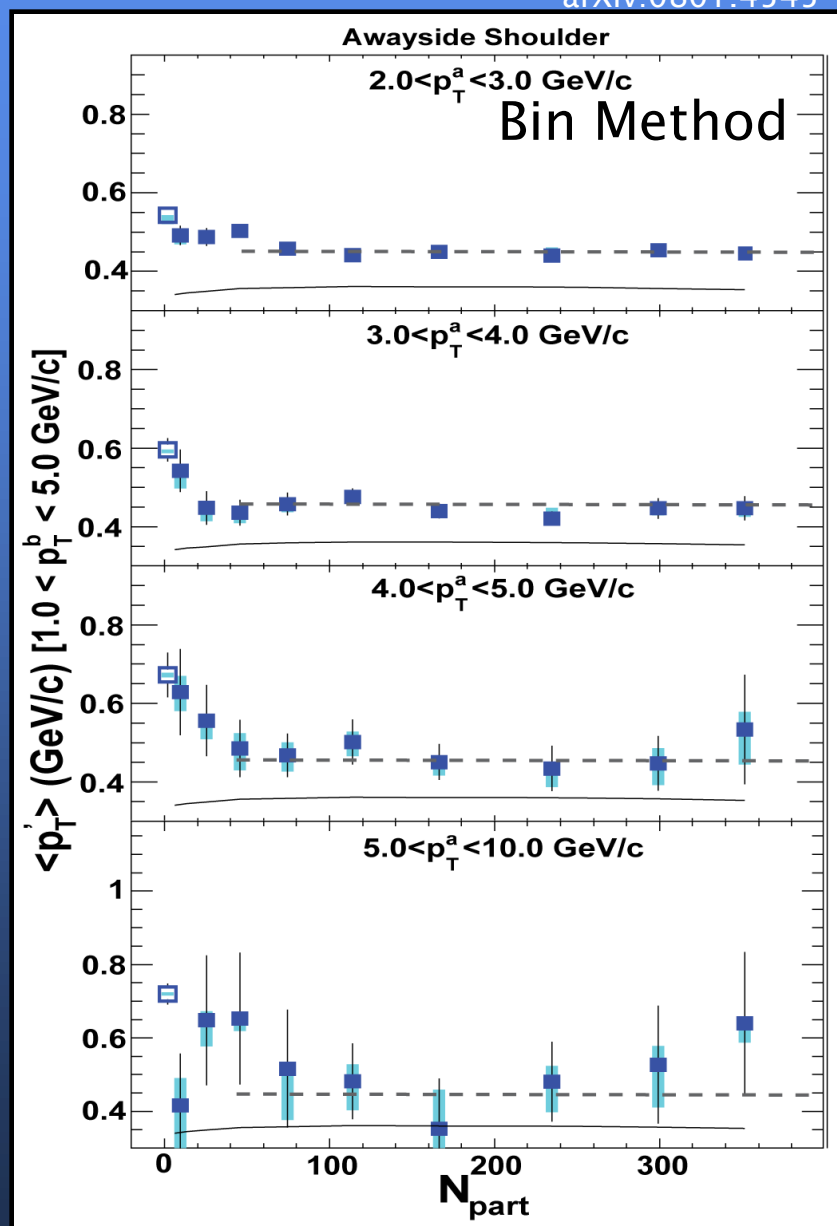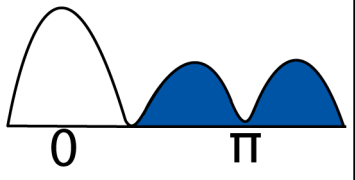
p-p baseline:
 - Spectral shape depends
   on trigger p_T selection
   ($0.55 \rightarrow 0.73$ GeV/c)

Mid-Central $\rightarrow$ Central Au-Au:
 - Medium response dominates
   the shoulder bin (>50 N_{part})

 - Softer than p-p away-side

 - Little dependence on trigger
   p_T selection (~0.45 GeV/c)

Awayside Shoulder

Bin Method

$2.0 < p_T^a < 3.0$ GeV/c

$3.0 < p_T^a < 4.0$ GeV/c

$4.0 < p_T^a < 5.0$ GeV/c

$5.0 < p_T^a < 10.0$ GeV/c

$\langle p_T' \rangle$ (GeV/c) [$1.0 < p_T^b < 5.0$ GeV/c]
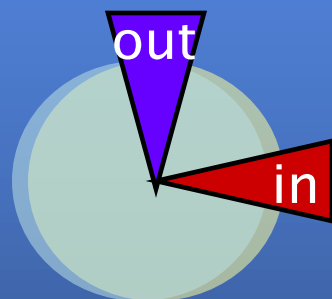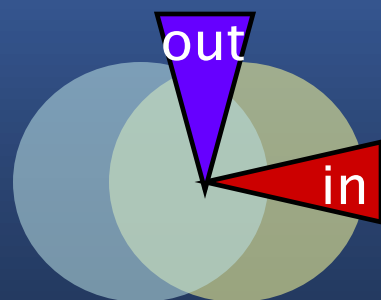
N_{part}

Away-side by Geometry

Reaction-Plane Binned Triggers from Run 7 with RXPN Detector:
- Reaction-plane resolution sys errors – Black lines (correlate in-out)
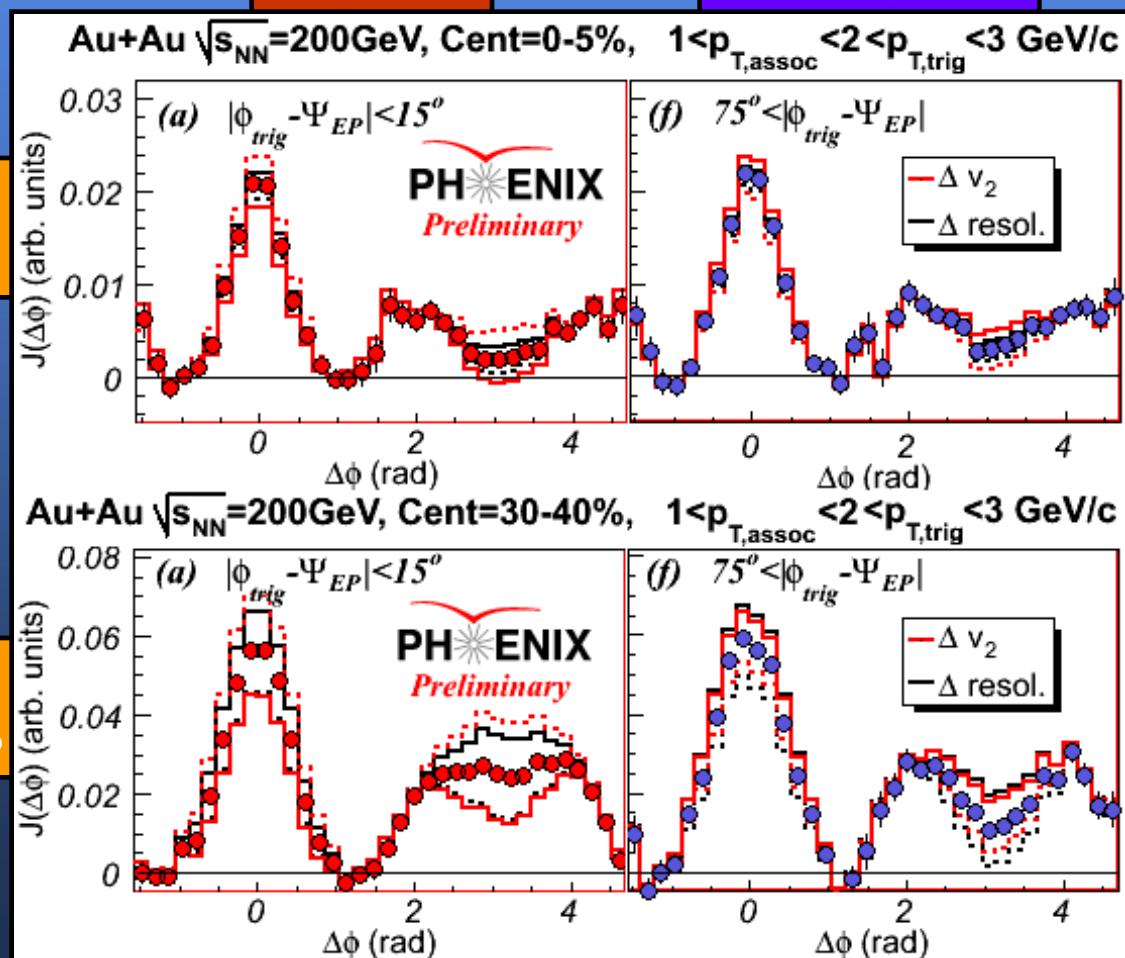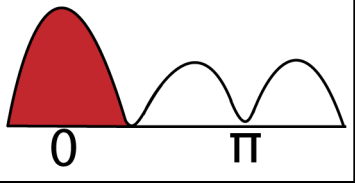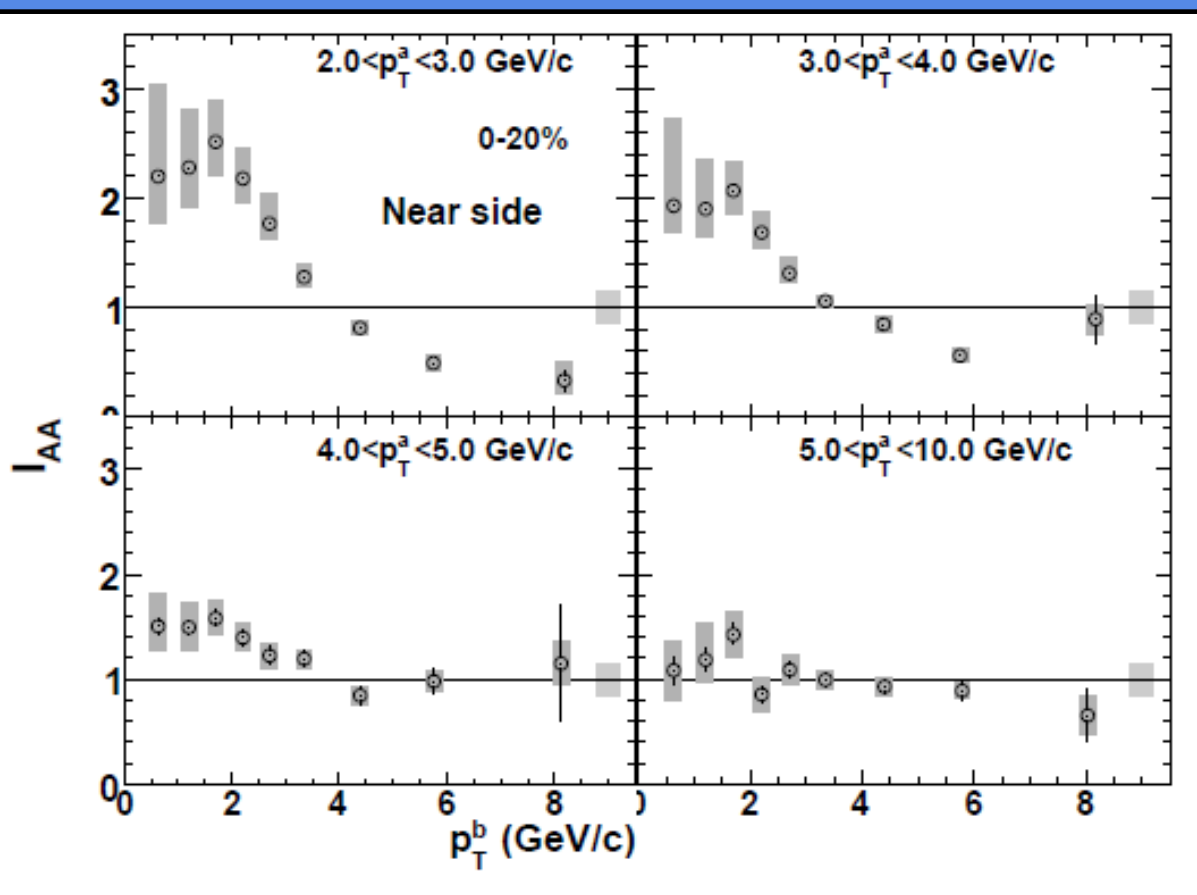- BBC-RXPN v_2 sys errors – Red lines (anti-correlate in-out)

in-plane **out-of-plane**

Cent 0-5%

Cent 30-40%

Near-side Enhancement

2.0<p_T^a<3.0 GeV/c

0-20%

Near side

3.0<p_T^a<4.0 GeV/c

4.0<p_T^a<5.0 GeV/c

5.0<p_T^a<10.0 GeV/c

I_{AA}

p_T^b (GeV/c)
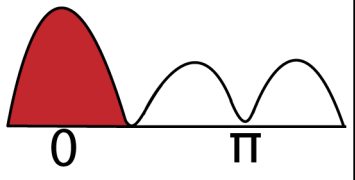
- Near-side enhancement at low partner p_T

- No enhancement or suppression at highest p_T

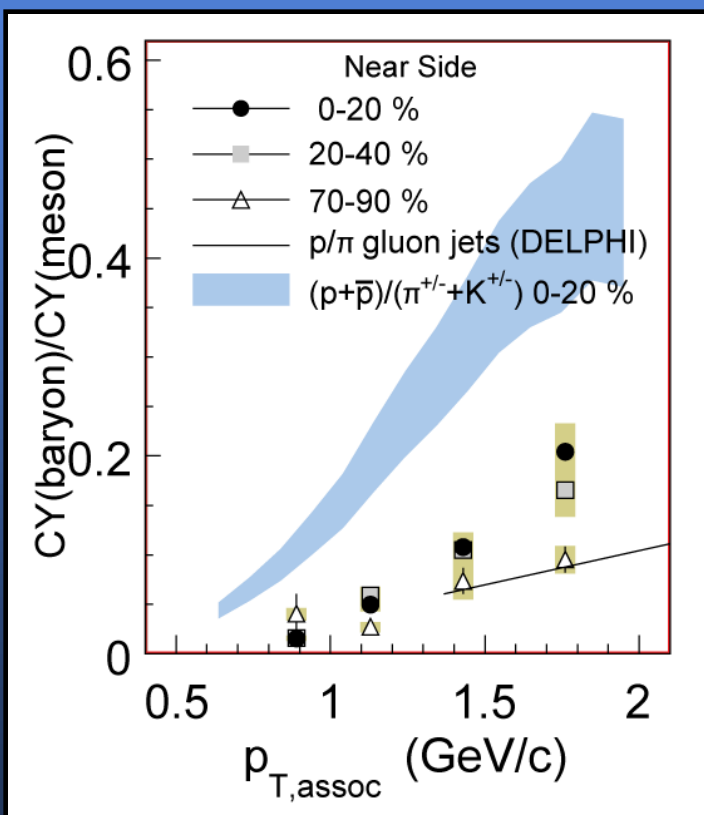- Apparent "suppression" at low p_T triggers and high p_T partners

arXiv:0801.4545

$$I_{aa} = \frac{1/N_{Au+Au}^{A} \times N_{Au+Au}^{AB}}{1/N_{p+p}^{A} \times N_{p+p}^{AB}}$$
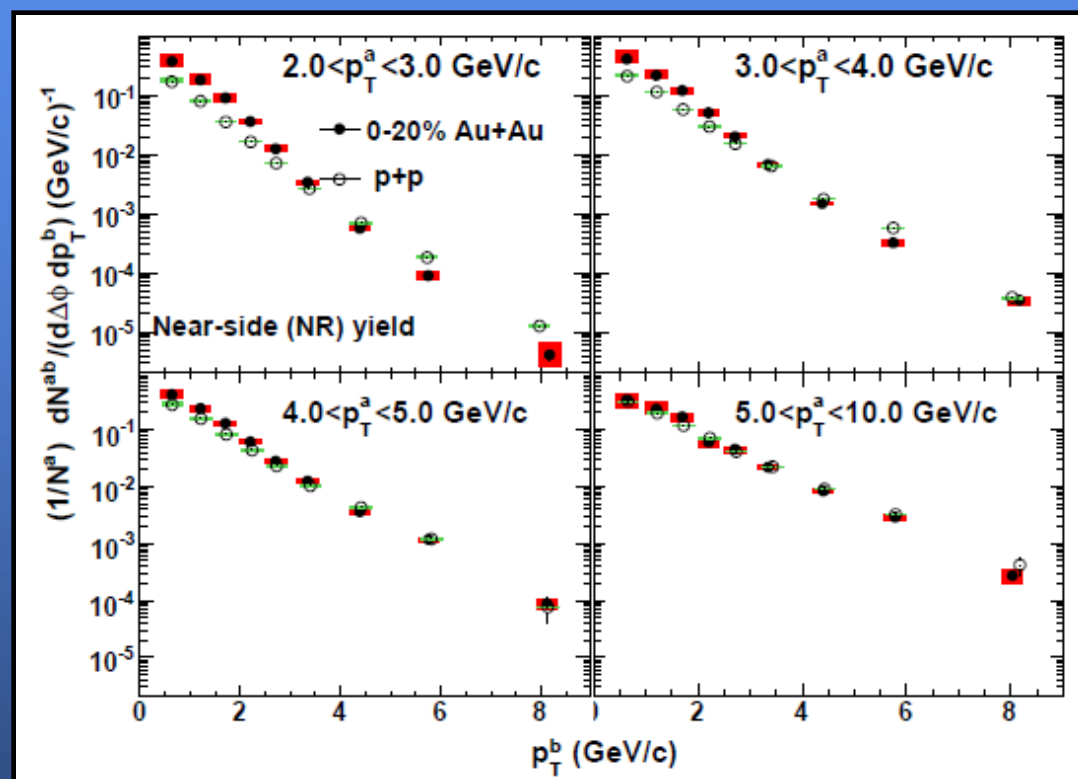
Near-side Composition & Spectra

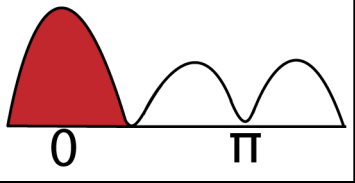- Near-side Baryon/Meson ratio increases in central collisions
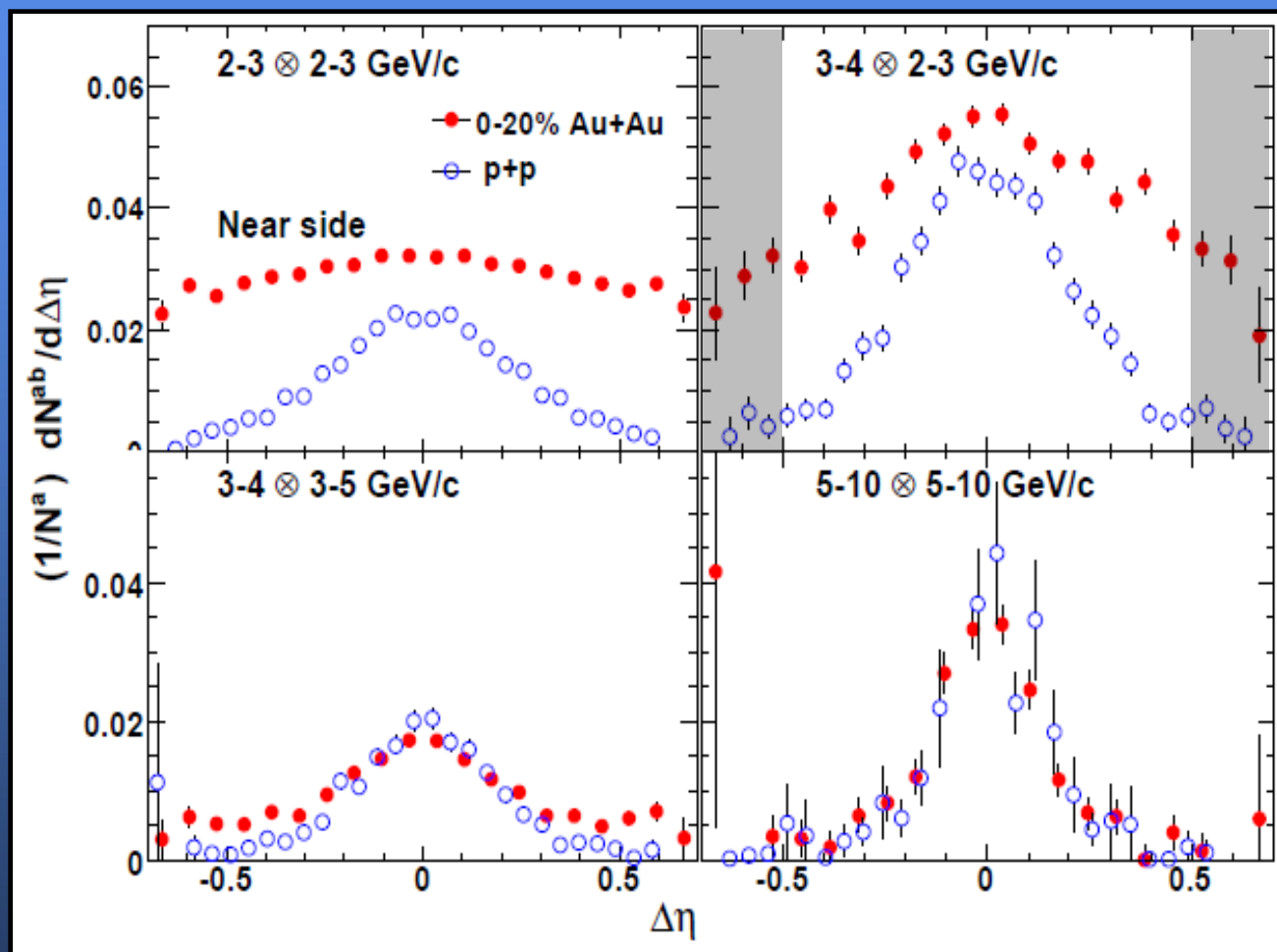

data from: arXiv:0712.3033

arXiv:0801.4545

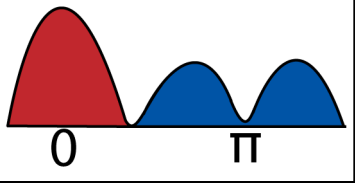- Near-side spectra are softer than p-p baseline at intermediate p_T

Near-side Ridge

- Broad Δη near-side enhancement measured in Au+Au collisions at intermediate p_T

- High p_T near-sides are similar

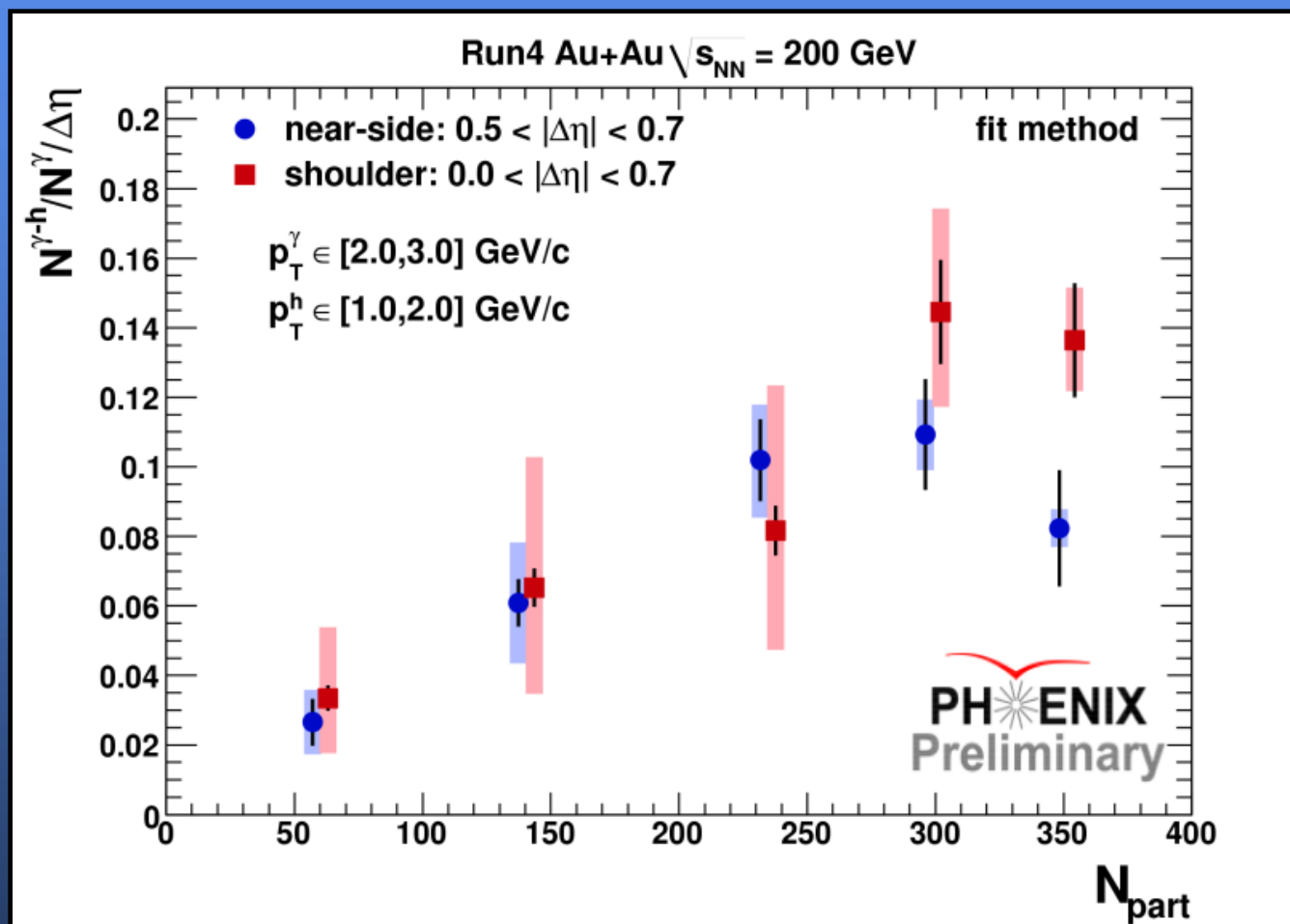- Intermediate p_T p+p near-side is narrower in Δη than central collisions

arXiv:0801.4545

- At intermediate p_T, little p-p jet beyond Δη > 0.5
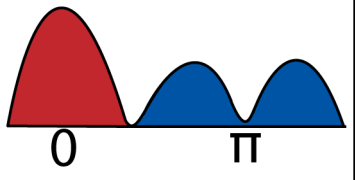
- Away-side shoulder and near-side ridge share a common centrality dependence

- Scale similarity here is largely a factor of p_T selection

Run4 Au+Au $\sqrt{s_{NN}}$ = 200 GeV

fit method

- near-side: $0.5 < |\Delta\eta| < 0.7$
- shoulder: $0.0 < |\Delta\eta| < 0.7$

$p_T^{\gamma} \in [2.0, 3.0]$ GeV/c
$p_T^{h} \in [1.0, 2.0]$ GeV/c

$N^{\gamma-h}/N^{\gamma}/\Delta\eta$

N_{part}

PH*ENIX
Preliminary

PHENIX poster (Chin-Hao Chen)
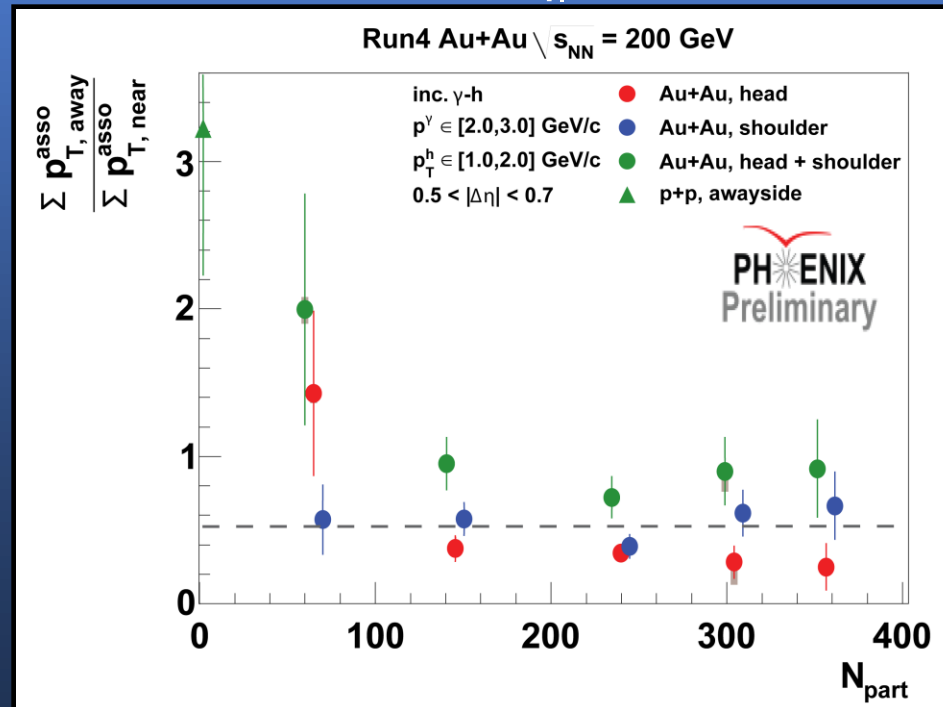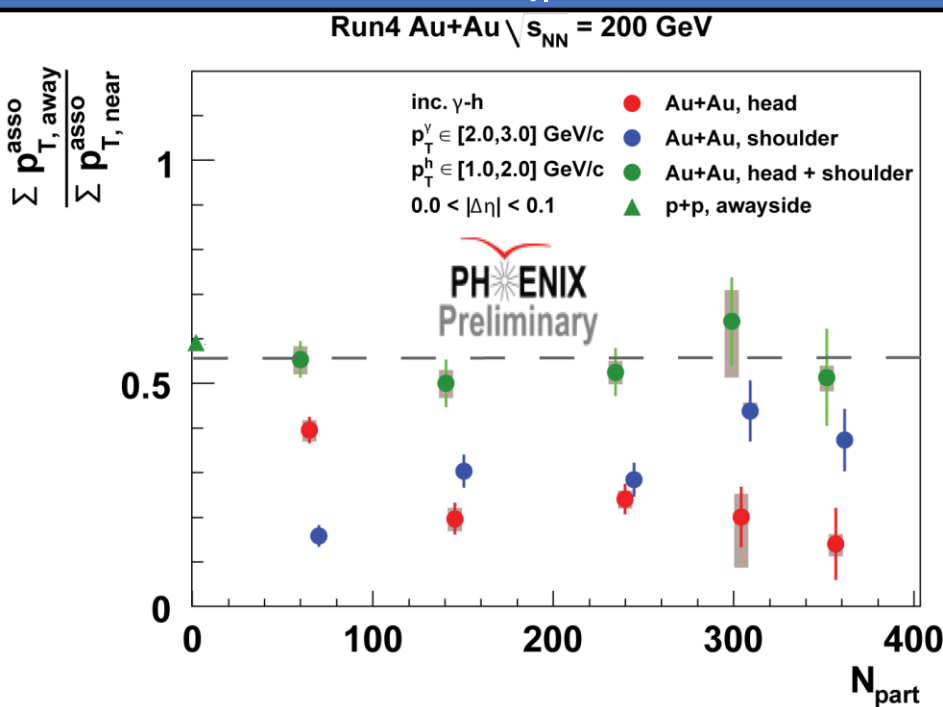
Connections - Balance

$$\sum p_T^{NEAR}$$

$$\sum p_T^{AWAY}$$
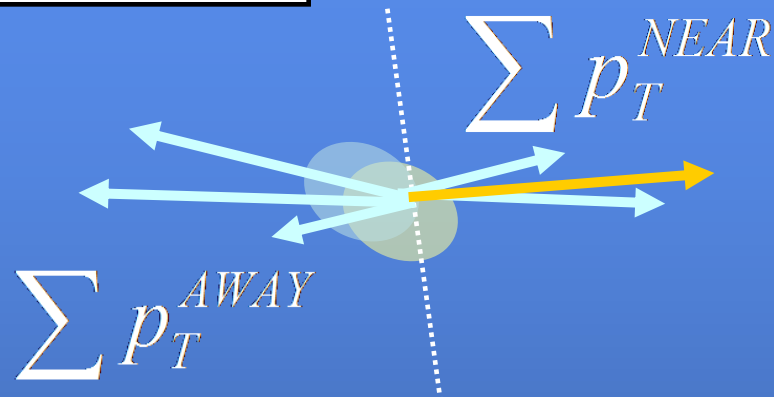
- Jet & Ridge balances Shoulder & Head

- Ridge & Shoulder balance separately!

0.0 < |Δη| < 0.1

0.5 < |Δη| < 0.7

Run4 Au+Au √s$_{NN}$ = 200 GeV

inc. γ-h
$p_T^γ$ ∈ [2.0,3.0] GeV/c
p_T^h ∈ [1.0,2.0] GeV/c
0.0 < |Δη| < 0.1

● Au+Au, head
● Au+Au, shoulder
● Au+Au, head + shoulder
▲ p+p, awayside

PH*ENIX
Preliminary

Run4 Au+Au √s$_{NN}$ = 200 GeV

inc. γ-h
$p_T^γ$ ∈ [2.0,3.0] GeV/c
p_T^h ∈ [1.0,2.0] GeV/c
0.5 < |Δη| < 0.7

● Au+Au, head
● Au+Au, shoulder
● Au+Au, head + shoulder
▲ p+p, awayside

PH*ENIX
Preliminary
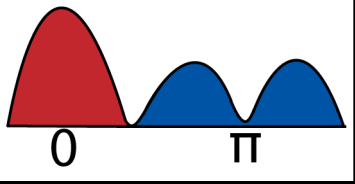
Connections - Spectra

PHENIX poster (Chin-Hao Chen)

Run4 Au+Au $\sqrt{s_{NN}}$ = 200 GeV Cent 0-20%

$p_T^\gamma \in [2.0, 3.0]$ GeV/c fit method
- - - - $|1/s| = 0.44(4)$
- · - · $|1/s| = 0.36(2)$
· · · · · $|1/s| = 0.32(2)$ (inclusive)

PH✷ENIX
Preliminary

● Au+Au near: (x10) $0.5 < |\Delta\eta| < 0.7$
○ p+p near: (x10) $0.0 < |\Delta\eta| < 0.7$
■ Au+Au away: $0.0 < |\Delta\eta| < 0.7$
□ p+p away: $0.0 < |\Delta\eta| < 0.7$
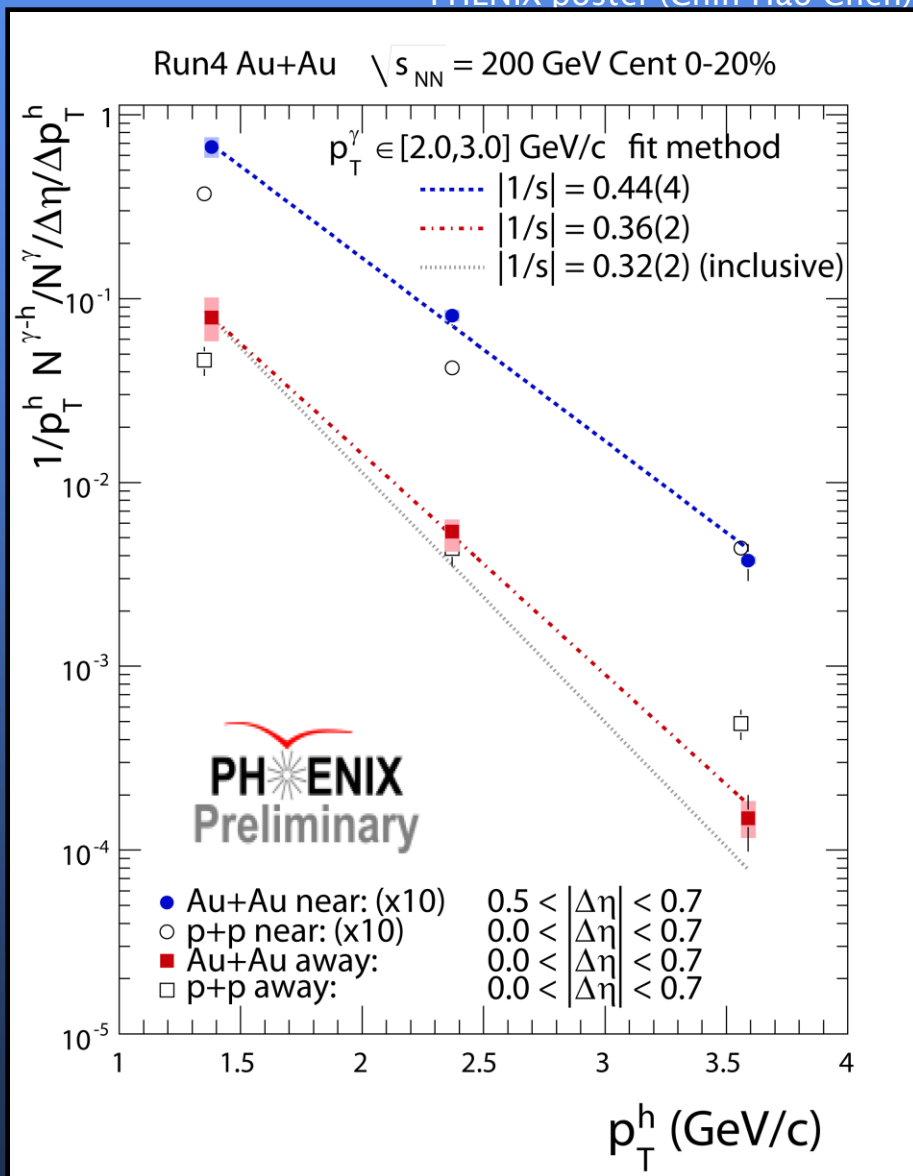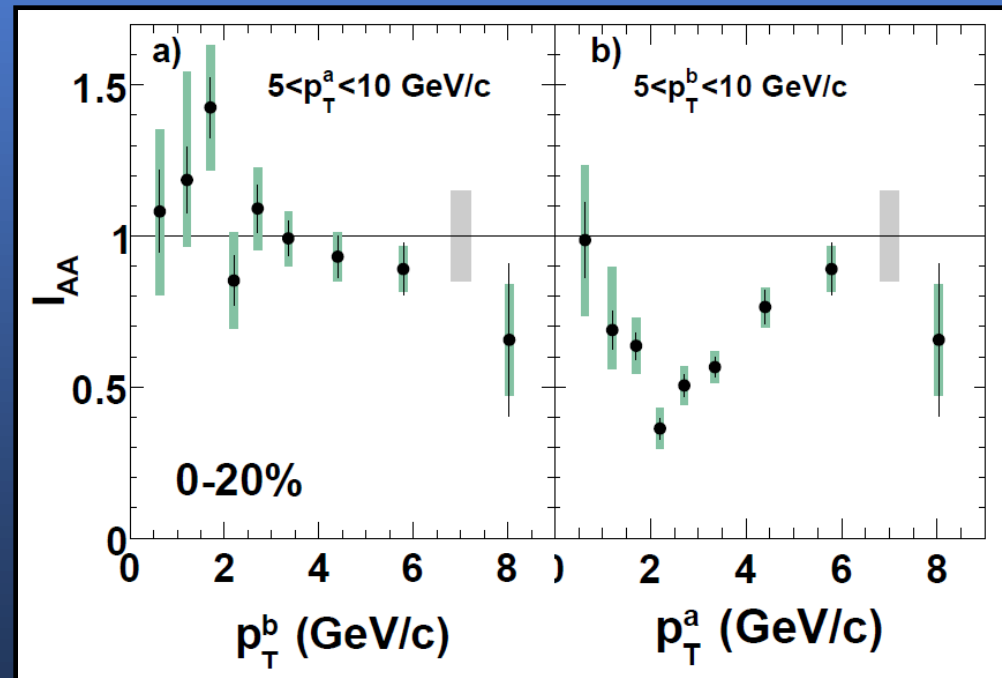
- Near-side ridge and away-side shoulder are both softer than p-p counterparts

- Near-side ridge is possibly harder than away-side shoulder

- Away-side shoulder is closest to inclusive hadron slope

Triggering on Medium Response

$\Delta\varphi_{AB}$

φ_A

φ_B

- I_{AA} trigger-partner anti-symmetry indicates not all triggers are jet fragments
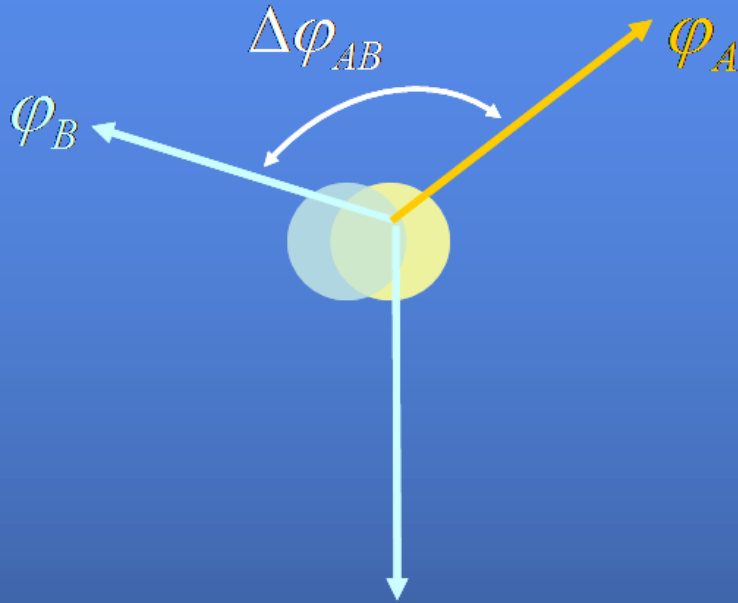
- 120 deg is a special angle

- Two-sided shoulder mechanisms could create structures at $\Delta\varphi = 0$ and $\Delta\varphi = \pi$ 1.1

a) $5 < p_T^a < 10$ GeV/c

b) $5 < p_T^b < 10$ GeV/c

I_{AA}

0-20%

p_T^b (GeV/c)

p_T^a (GeV/c)

arXiv:0801.4545

Summary

- PHENIX is measuring both **Ridge and Shoulder**
- Shoulder & Head variation consistent with contributions of both medium response and suppressed in-vacuum jet fragmentation
- Ridge and Shoulder measurements consistent with **medium response**, inconsistent with in-vacuum jet fragmentation
- Ridge & Shoulder share much of the **same behavior**
  - appear at similar p_T
  - similar centrality dependence
  - softer than p-p counterparts
  - baryon-meson ratios larger than jet fragmentation
  - balance p_T
- At low enough p_T, some triggers must come from medium response

Further:
    PHENIX posters on intermediate p_T correlations:
        Inc γ-h correlations – Chin-Hao Chen (PHENIX)
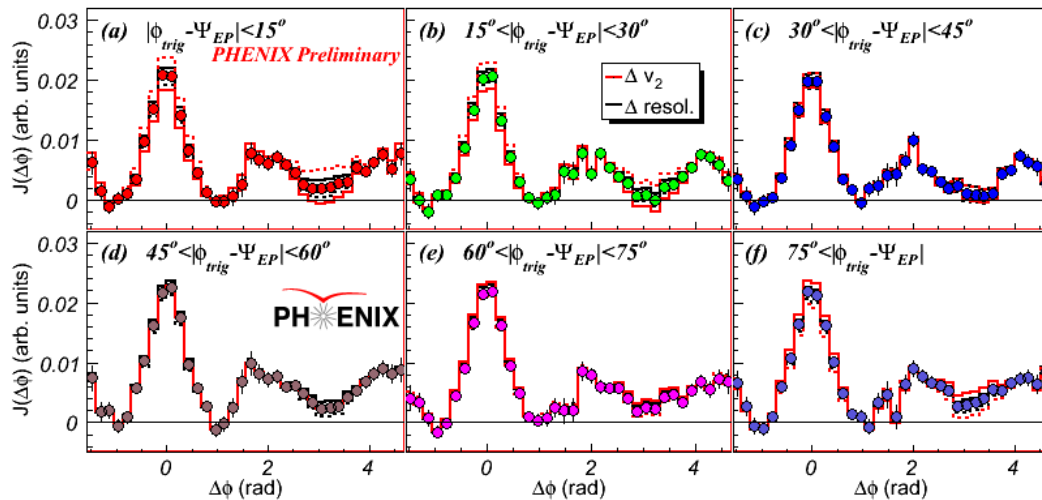   h-h correlations – Jiangyong Jia (PHENIX) – P165
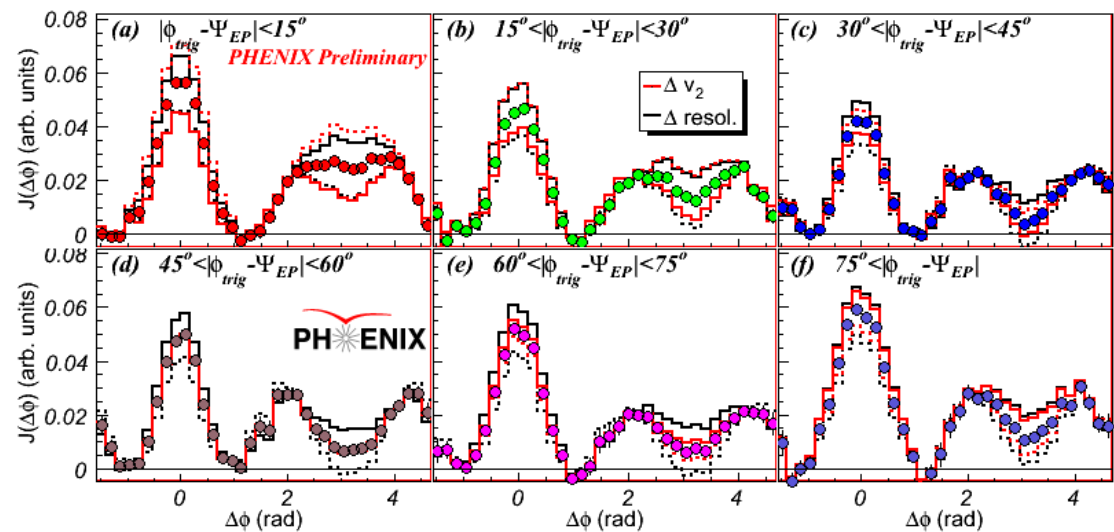
Backups

Cent 0-20%
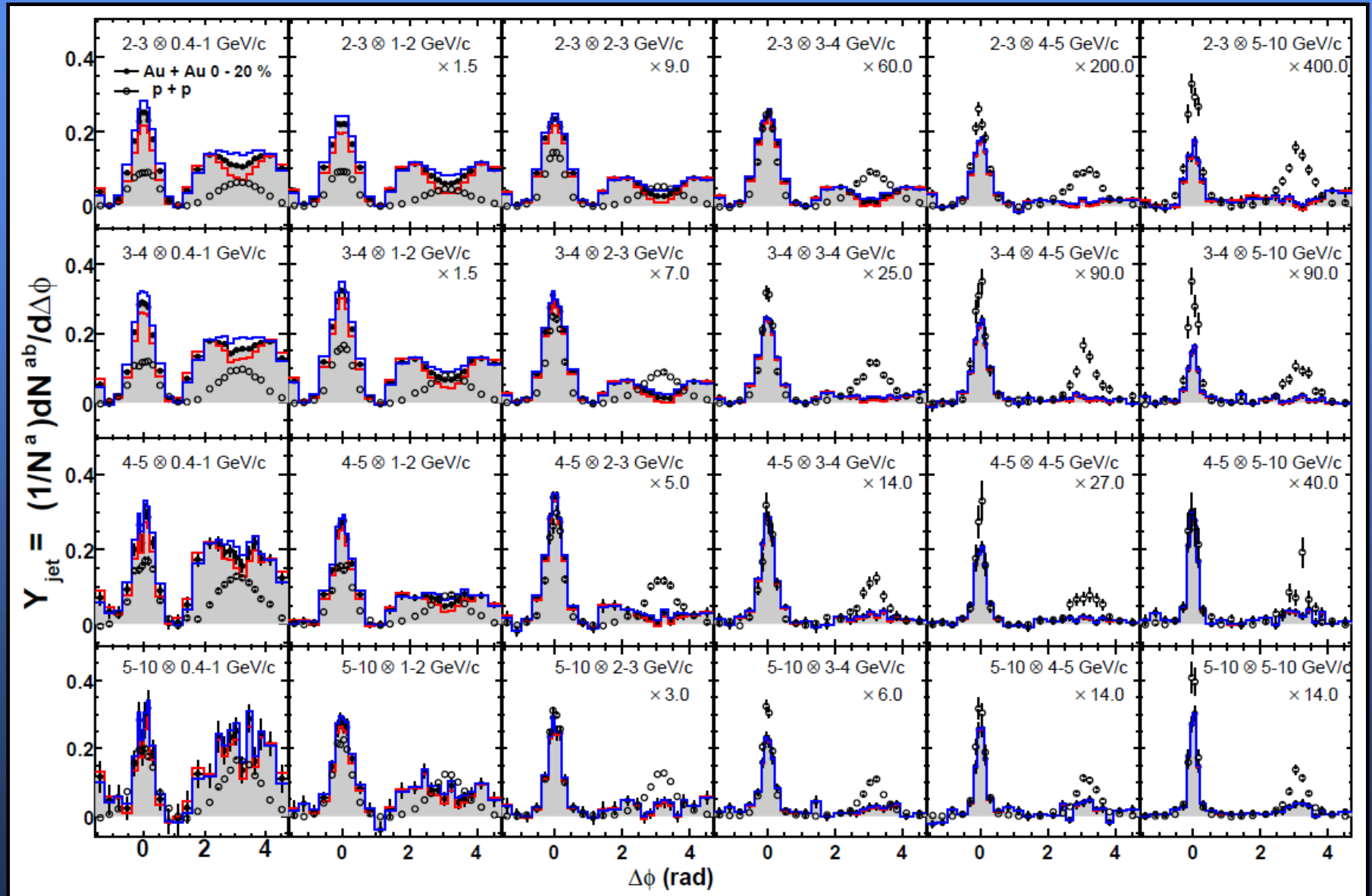
Cent 60-92%
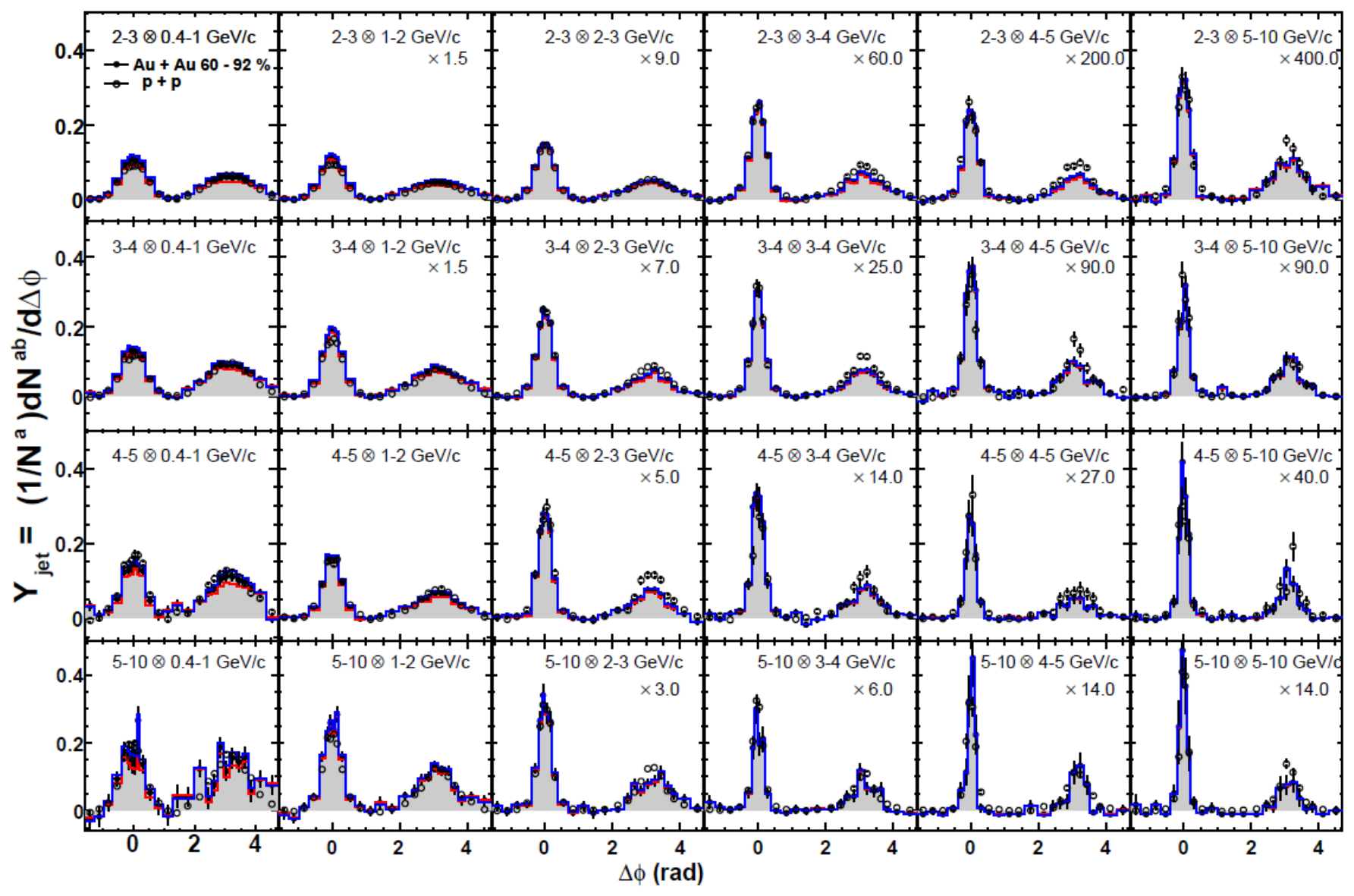
Au+Au $\sqrt{s_{NN}}$=200GeV, Cent=0-5%, 1<$p_{T,assoc}$<2 GeV/c, 2<$p_{T,trig}$<3 GeV/c

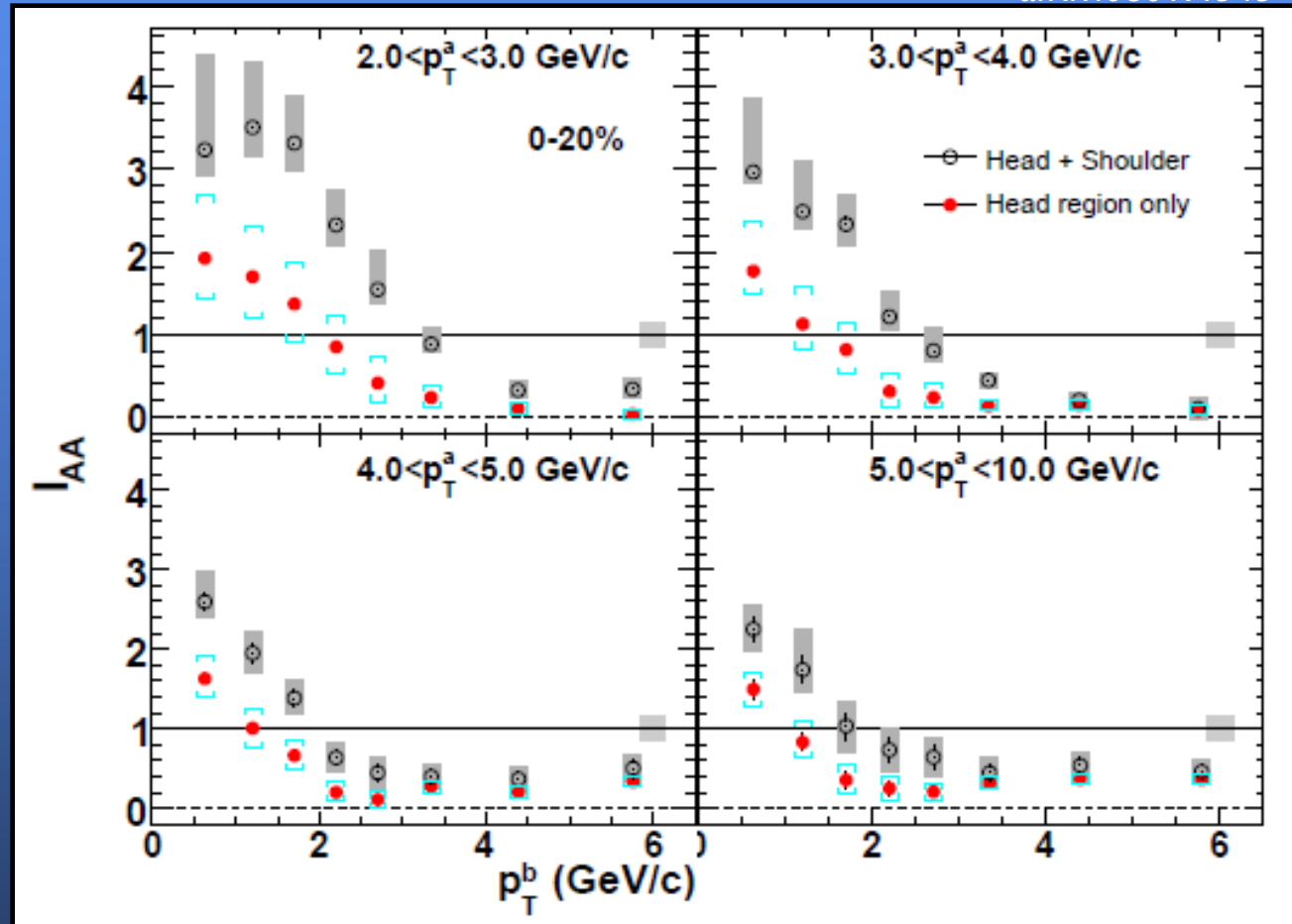=30-40%, 1<$p_{T,assoc}$<2 GeV/c, 2<$p_{T,trig}$<3 GeV/c

Fit Method Discussion
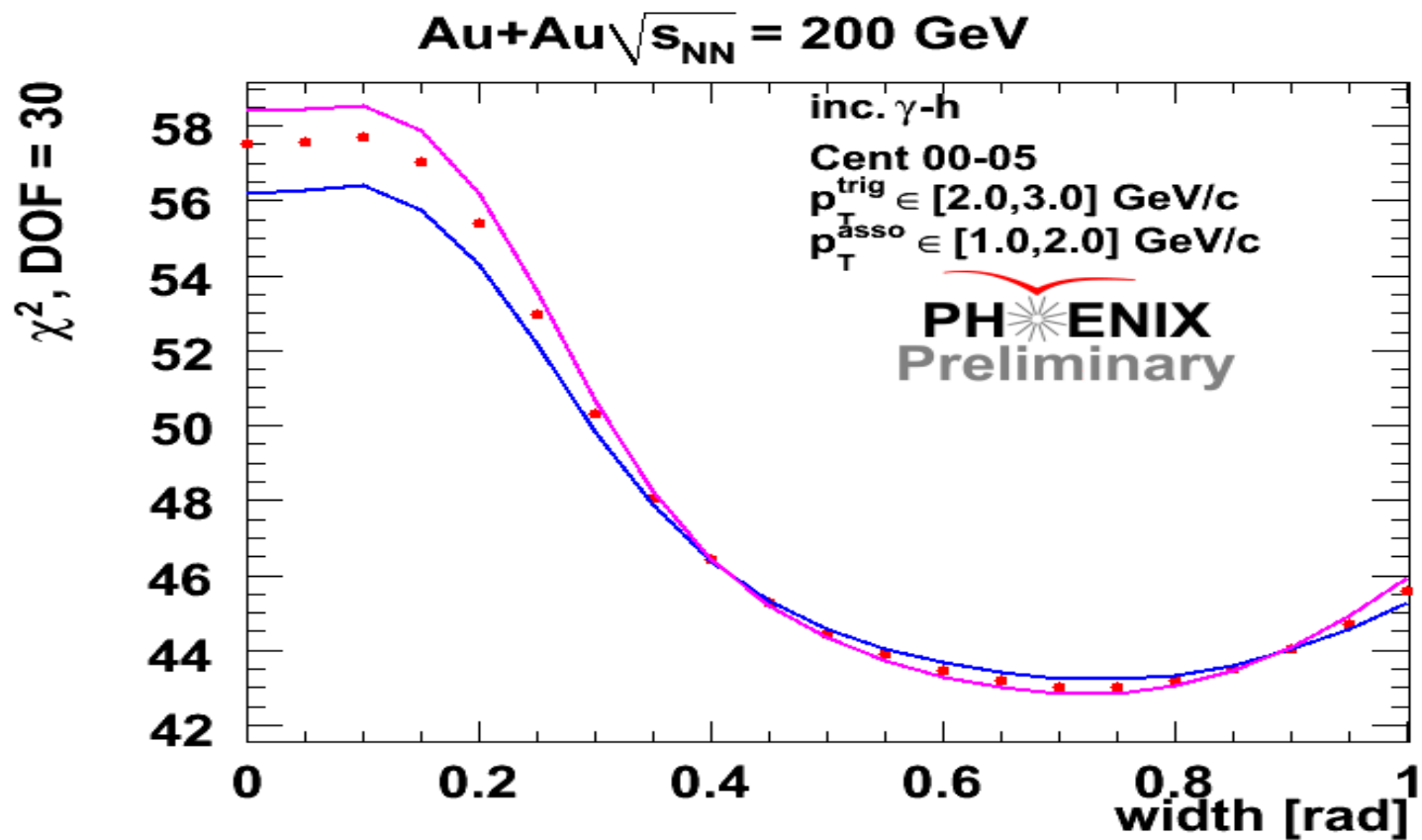
Away-side Shoulder Enhancement

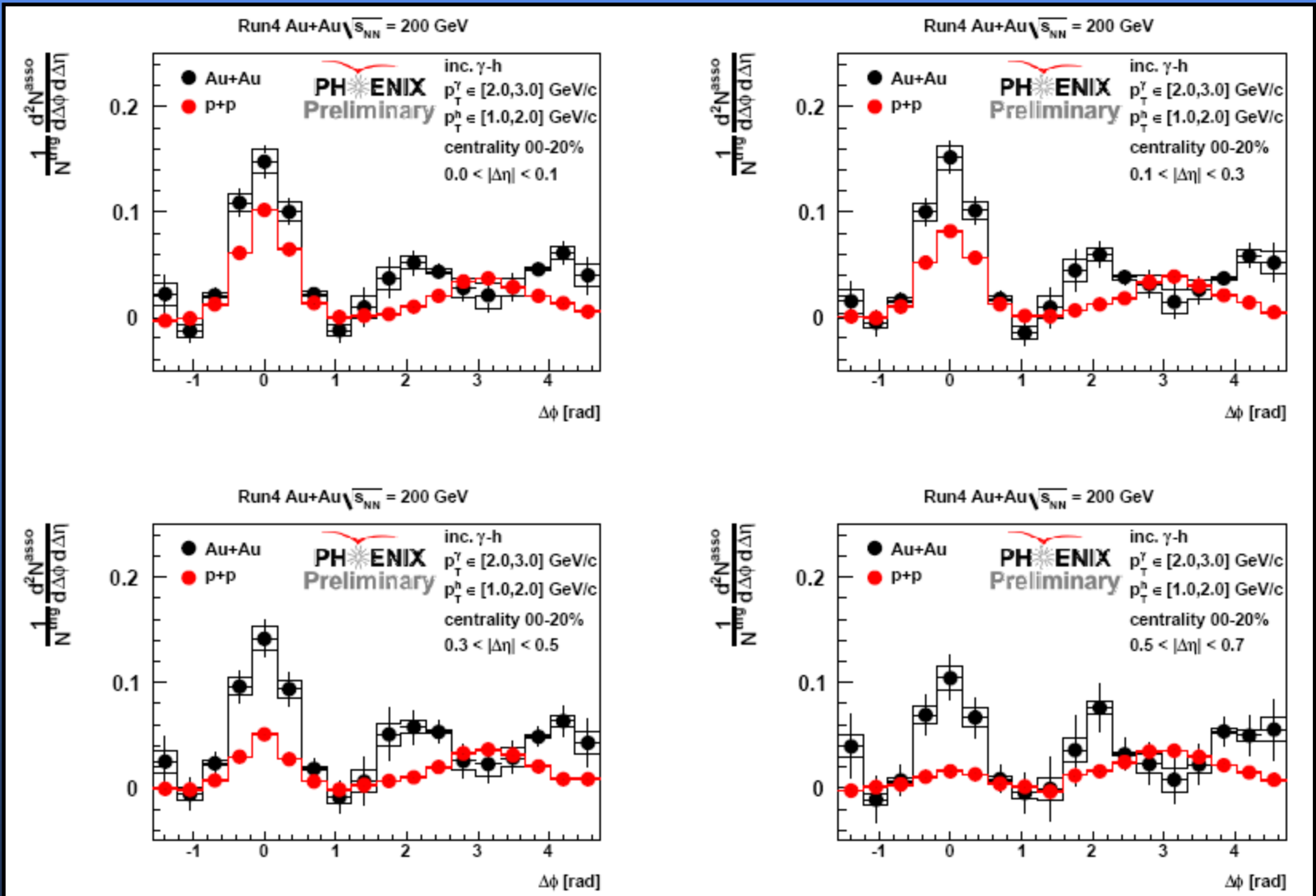Away-side enhancement over p-p baseline is limited to lower partner p_T

Away-side suppressed below p-p values at high p_T

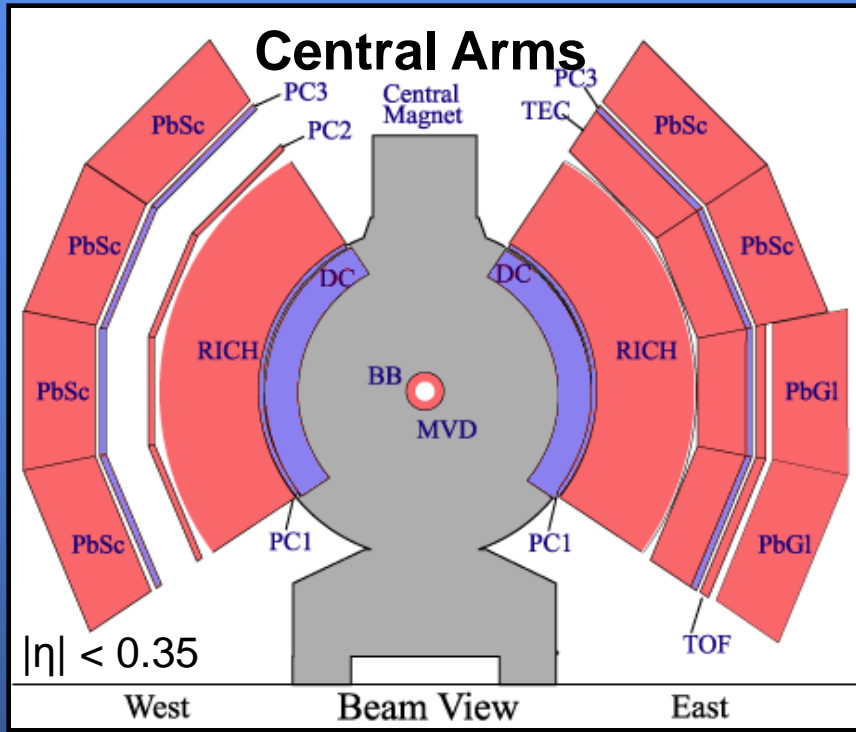Head and Shoulder suppressions similar at high pT

Head region also shows enhancement at low p_T due to contamination from Shoulder region
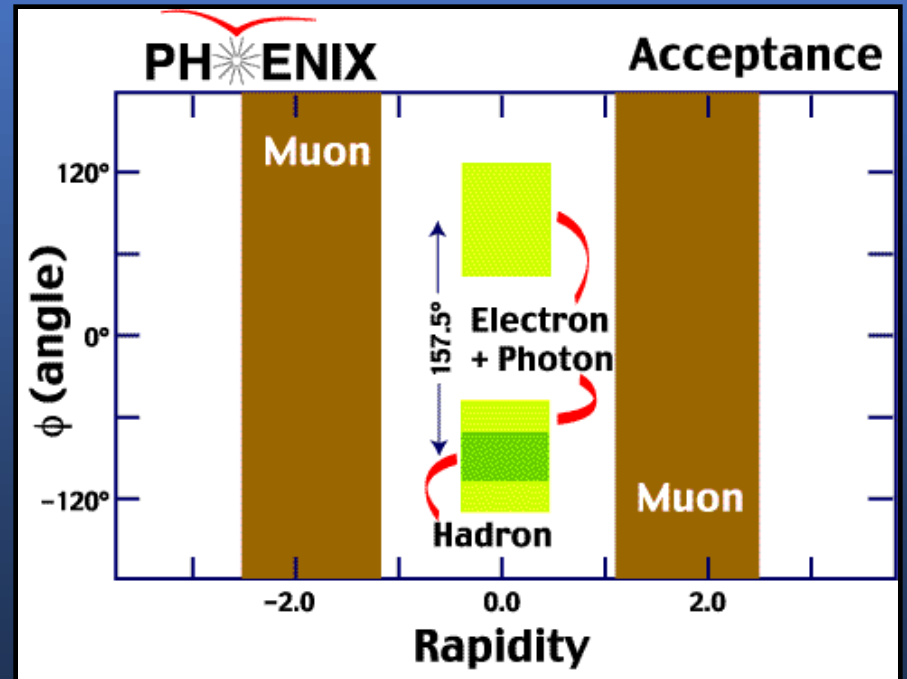
Inclusive γ-h Correlations

PHENIX Detector

Central Arms

|η| < 0.35

West   Beam View   East

Charged tracking from DC, PC1, and PC3 at mid rapidity, η.

Centrality and Reaction-plane from BBC and ZDC at large |η|.

PH✴ENIX   Acceptance

Muon

Electron + Photon

157.5°

Hadron

Muon

φ (angle)

Rapidity

Background Subtraction
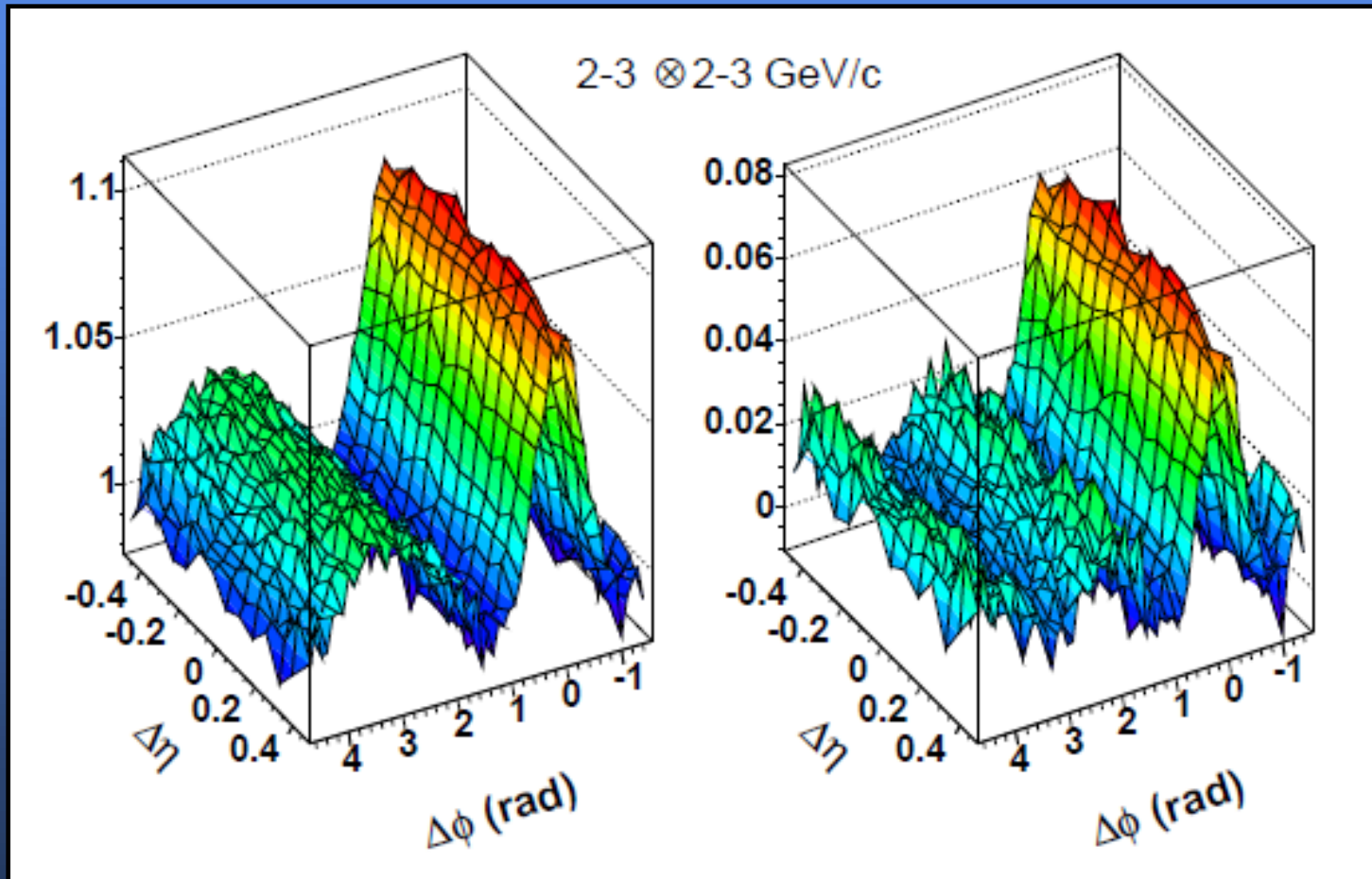
Acceptance Correction

Event N

Rolling buffer mixing technique

Event N-1

Pooled by Event type:
5cm zvertex
5% centrality

Event N-2

Event N-3

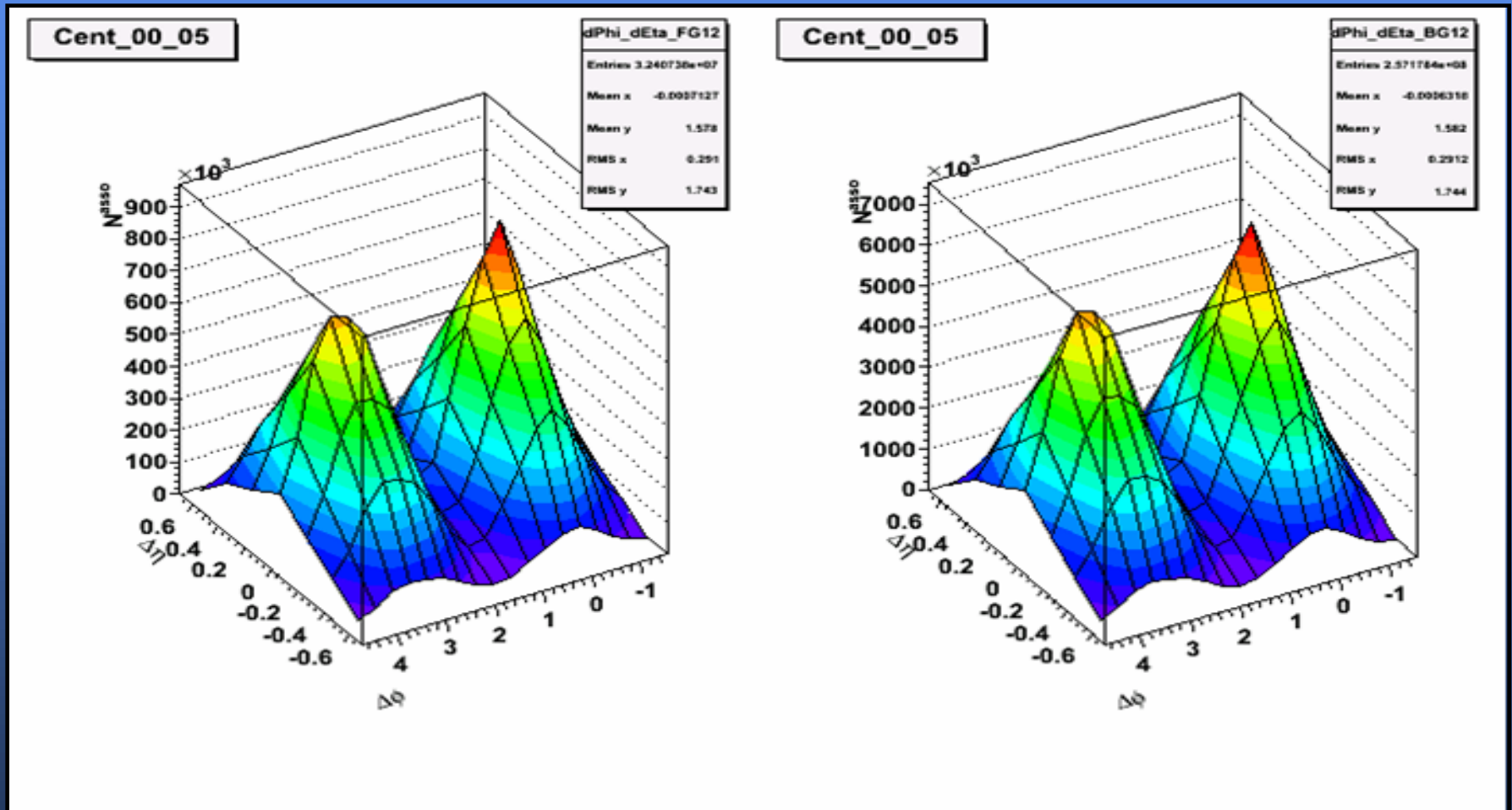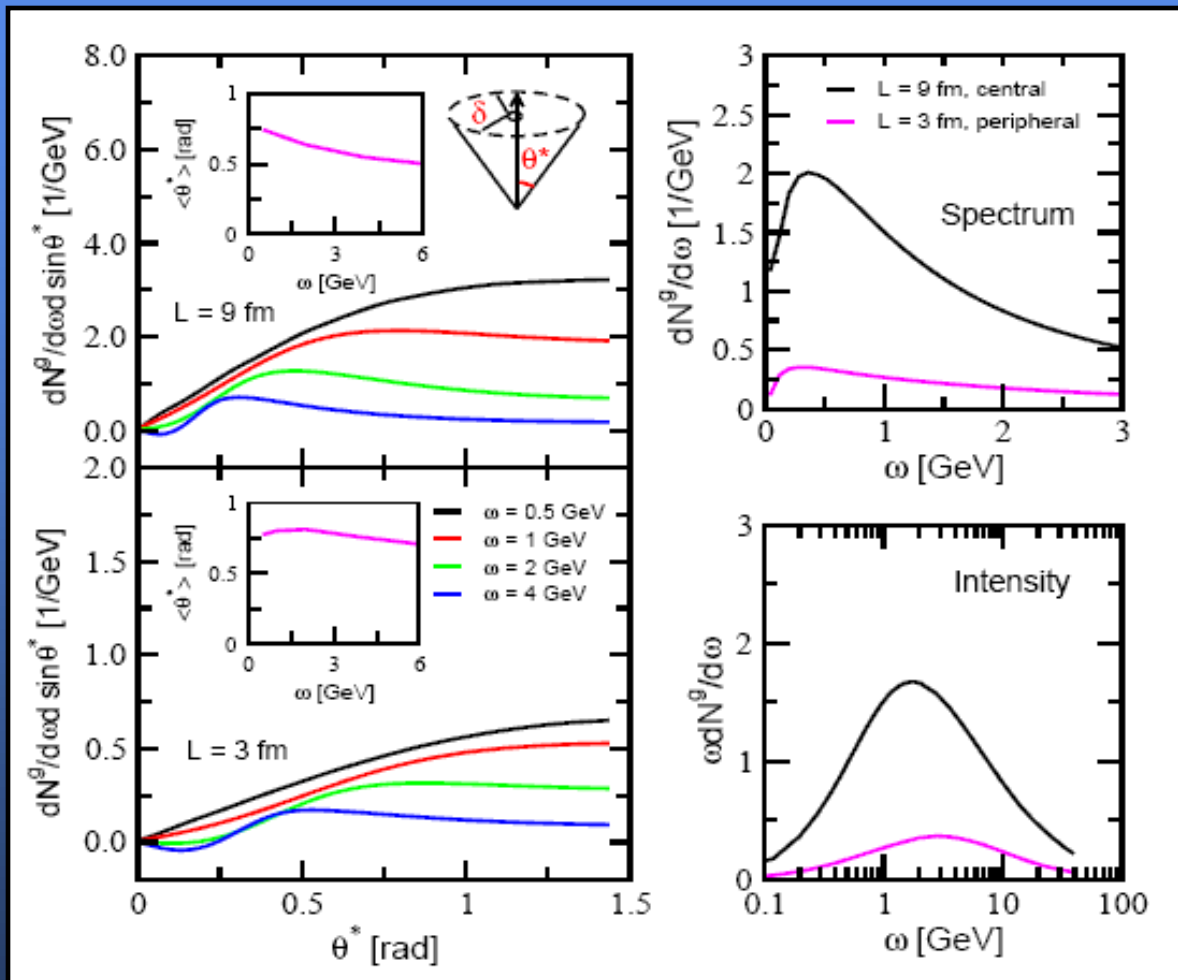Event N-4
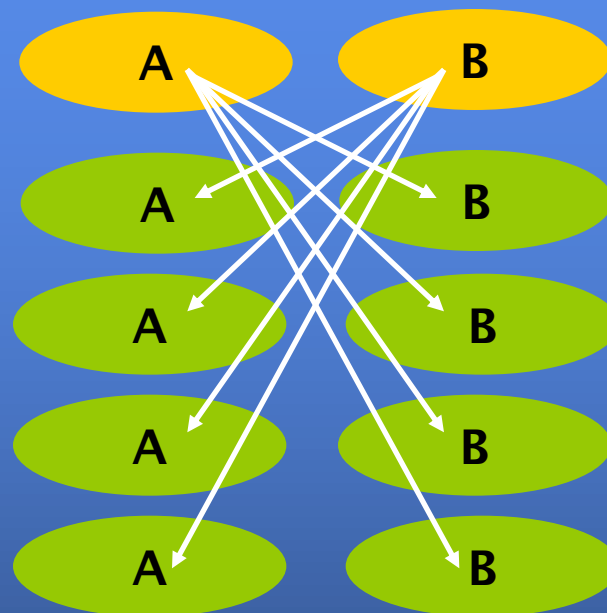
The two-arm acceptance effects are removed by building a correction from event mixing.

Acc(Δφ)

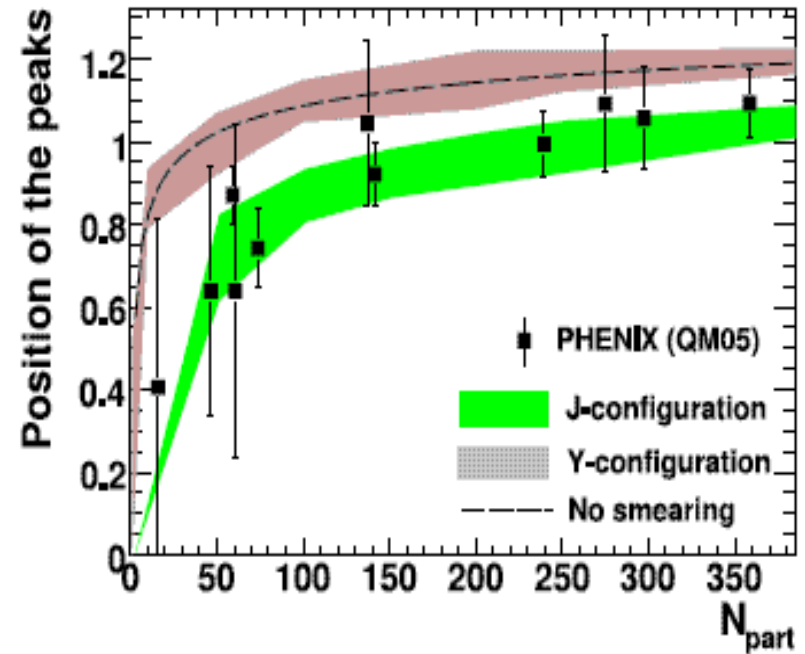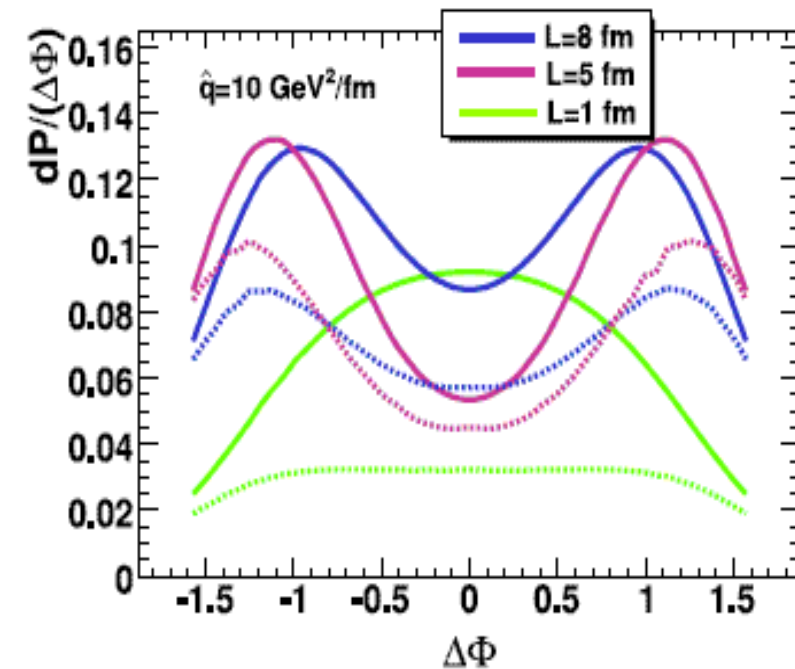0   ΔΦ_AB   π

2D Acceptance

Large Angle Scattering -- Vitev

Angles are typically smaller than observed

Average scattering angle falls with path length
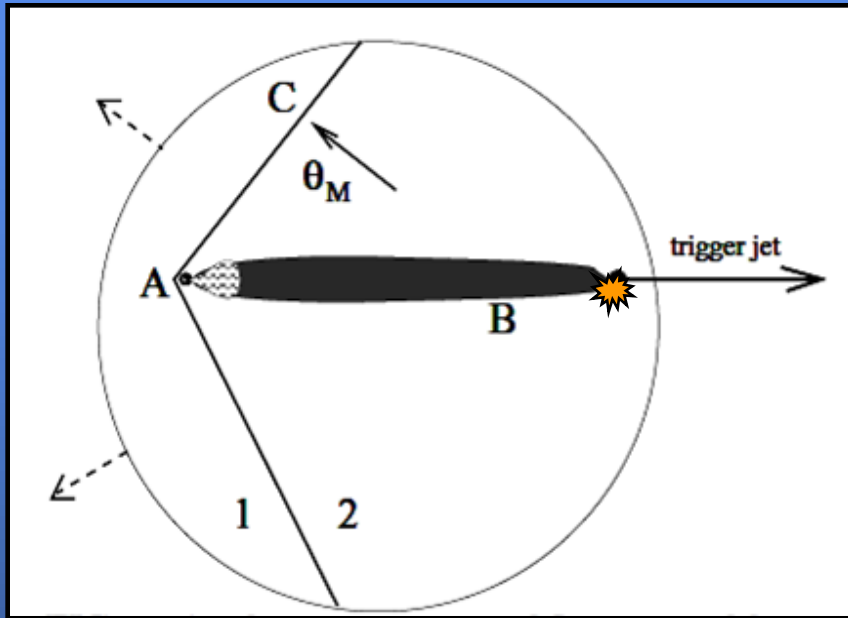
Contrasts our centrality dependence

hep-ph/0501255

Large Angle Scattering – Polosa, Salgado

Claim that the similar p_T windows restrict signal to a small number of splittings

Mach Cones

Casalderray,Shuryak,Teaney hep-ph/0411315
Stöcker, Nucl. Phys. **A750** (2005) 121

$$\cos(\theta_M) = c_S$$

$\theta_M = 1.2 \rightarrow c_s \sim 0.33$
(0.57 in QGP, 0.2 in hadron gas)

$D \sim 1.0\text{-}1.1 \rightarrow c_s \sim 0.45 - 0.54$
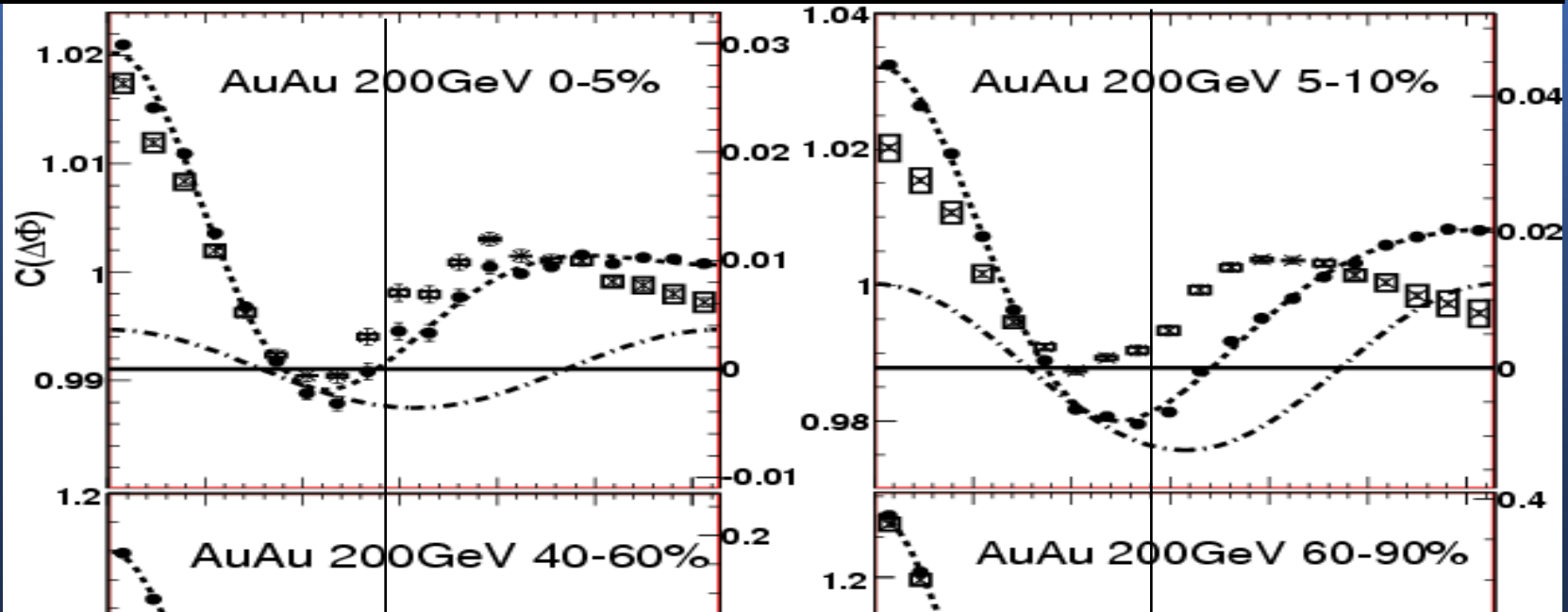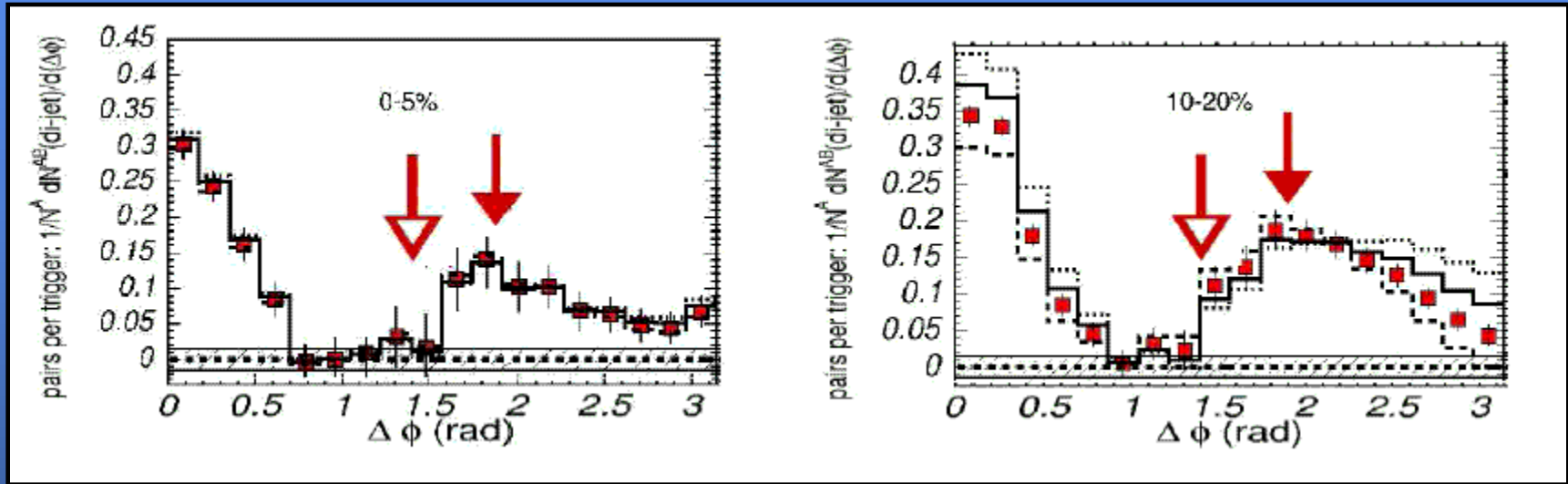
Reproduces large angles seen in the data

Expectation of little p_T dependence

Expectation of a beam energy dependence
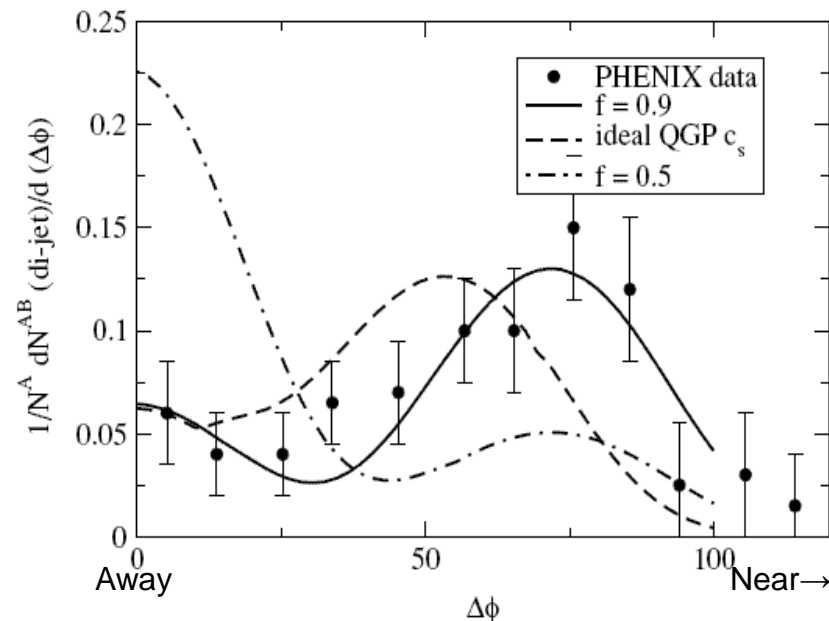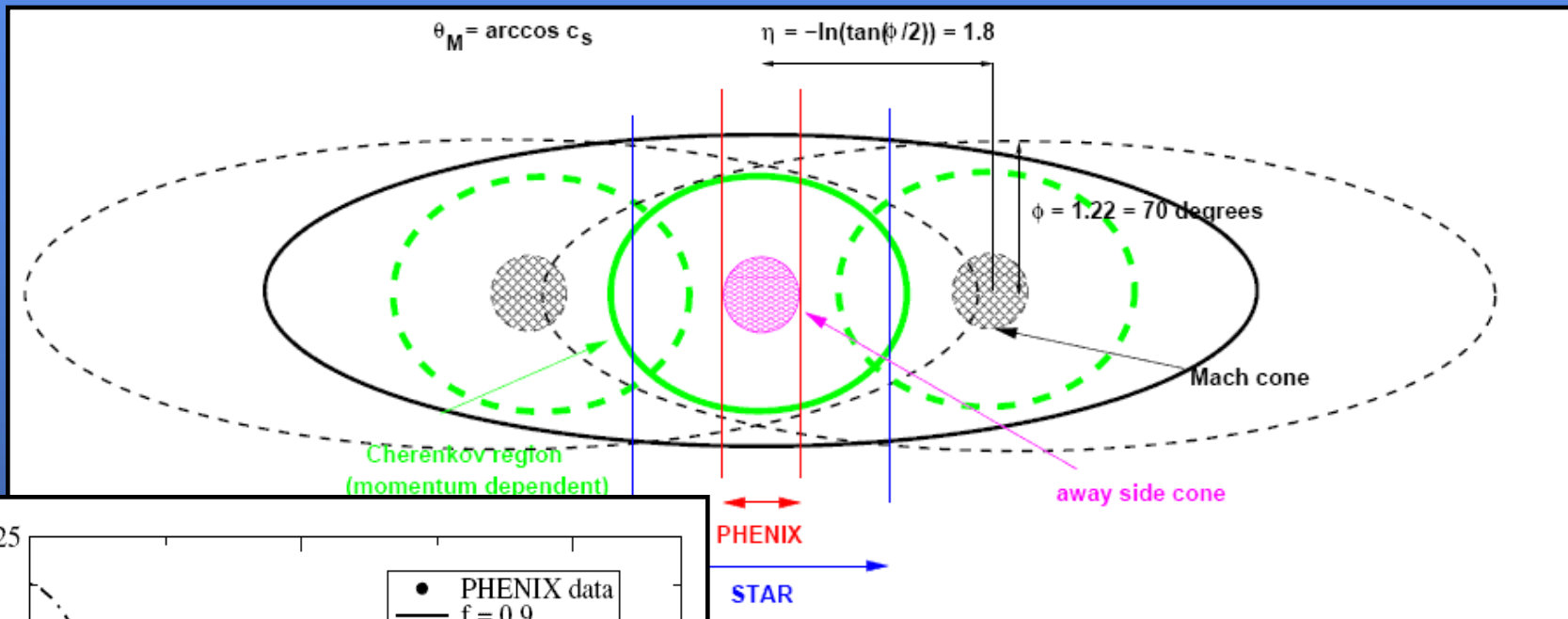
Mach Cones – Jorge & Edward

First-order phase transition would reflect some Mach Cone   hep-ph/0511263
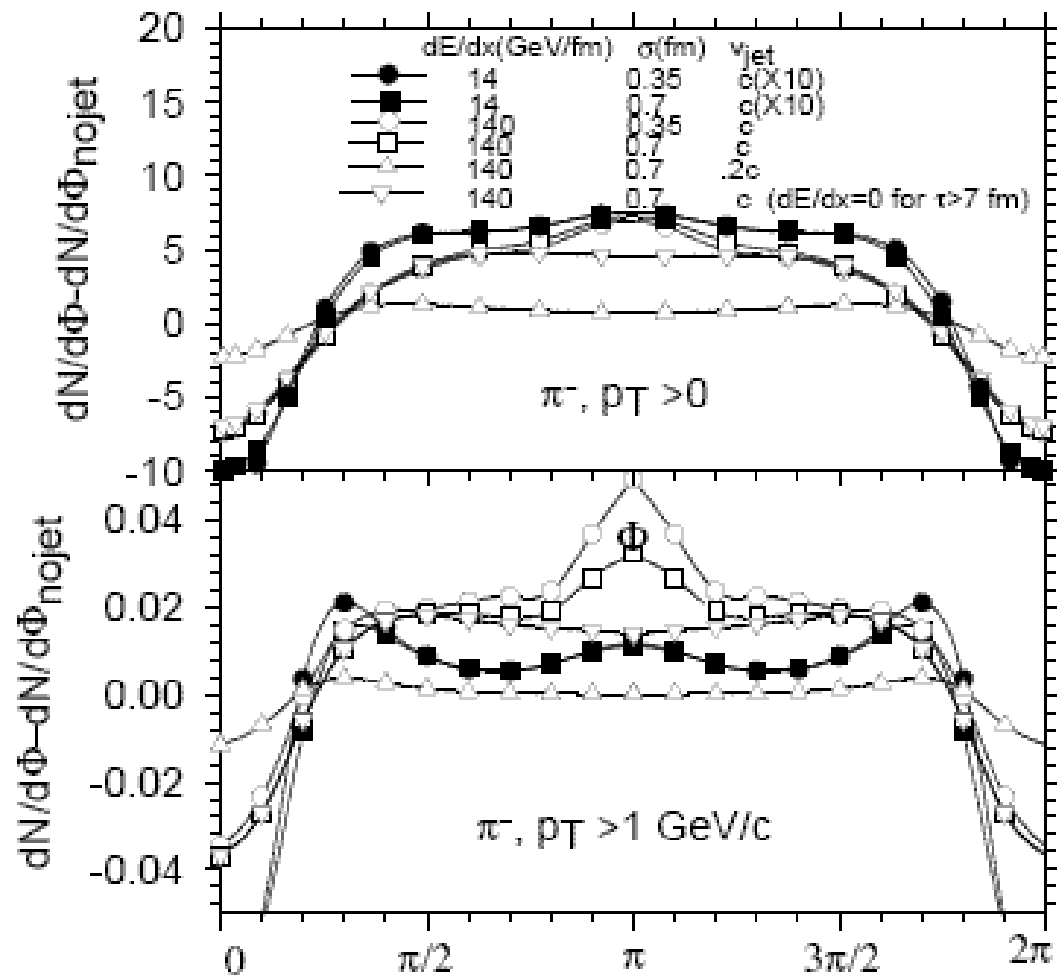
Mach Cones – Renk & Ruppert

Longitudinal flow improves the predicted Δφ signal from a Mach Cone

Match to the data requires large fractional energy loss to Mach cone

Mach Cones – Chaudhuri & Heinz

Assume lost energy is instantaneously thermalized in their hydro simulations
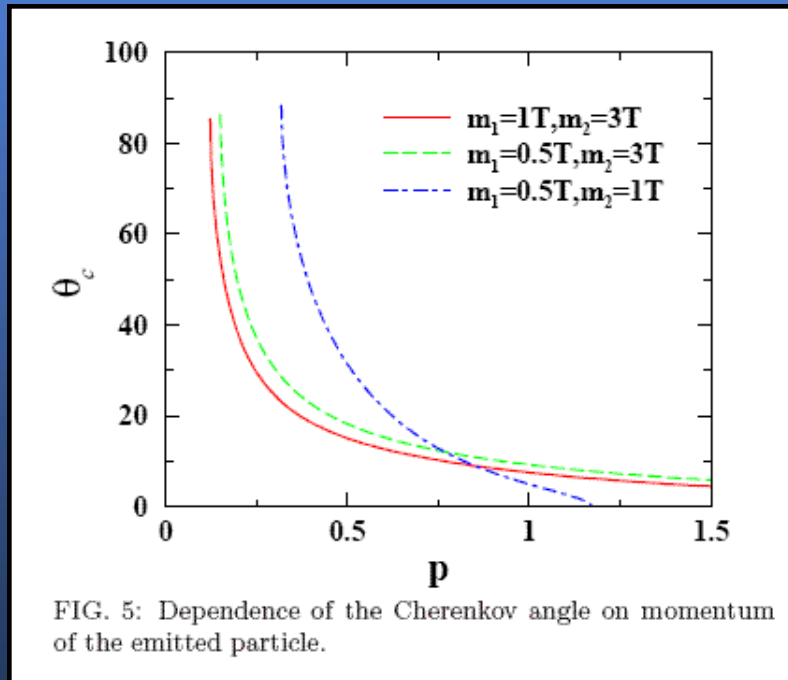
Extract no Mach cone signal

Large energy loss scenarios give "splash-back" signal
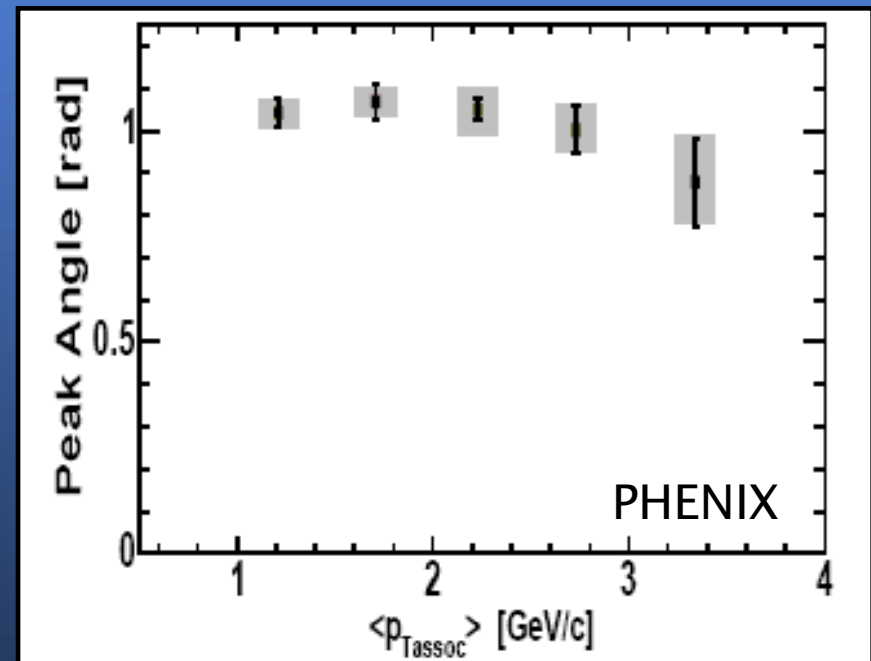
Cherenkov – Majumder, Wang

Cherenkov production has "a strong dependence on the gluon momentum"

"disappear for high-energy gluons"

Predict D values will shrink as associated momentum is increased.
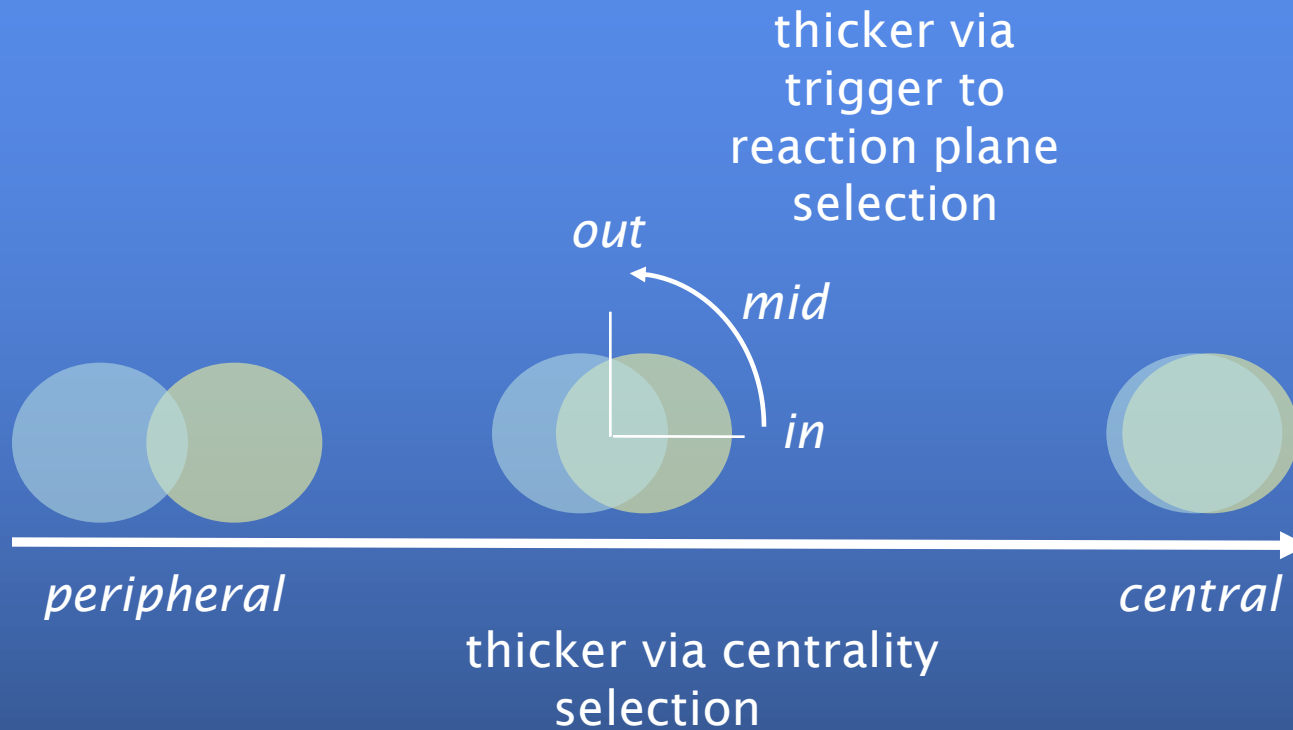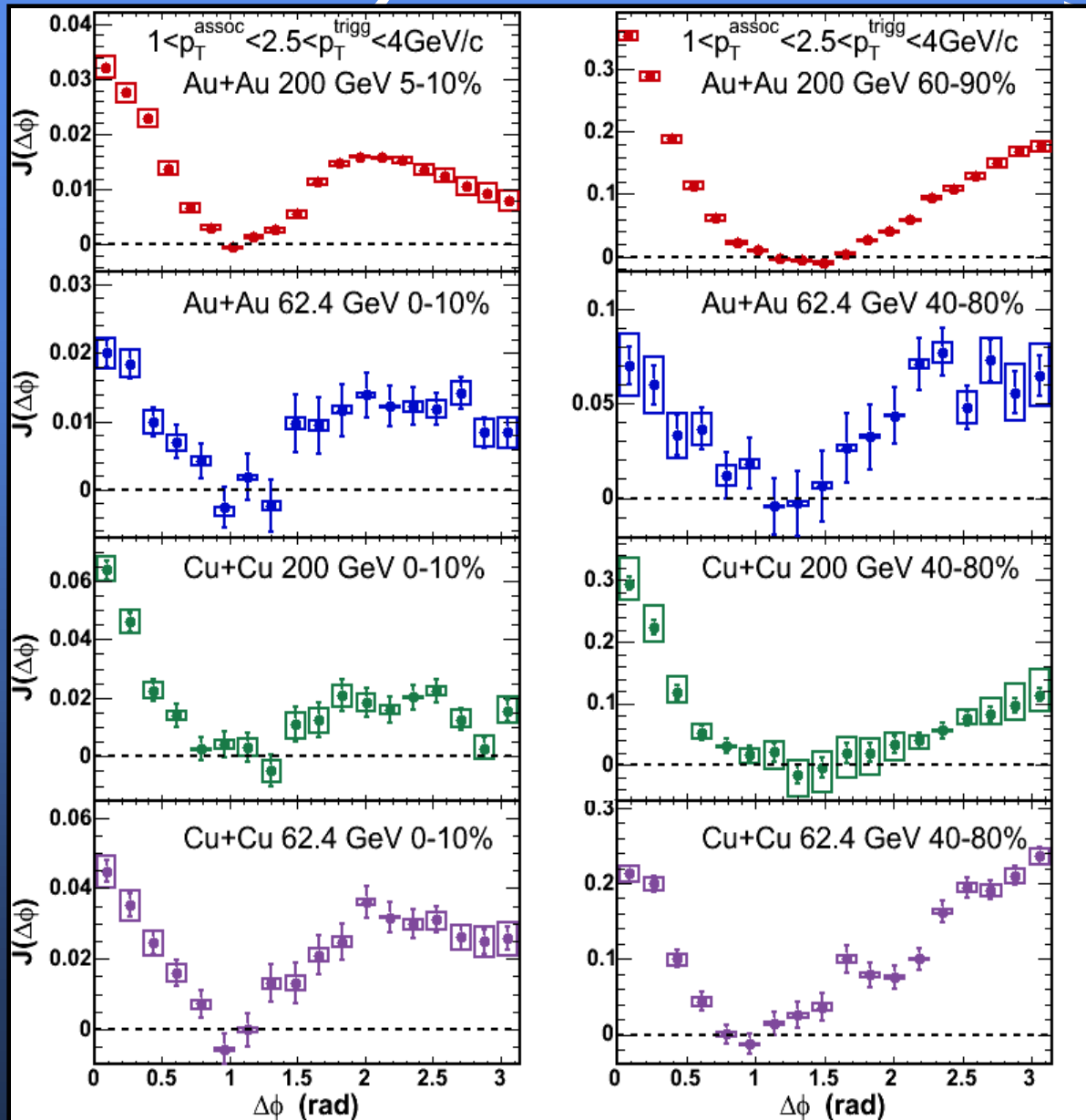

FIG. 5: Dependence of the Cherenkov angle on momentum of the emitted particle.

PRL **96,** 172302 (2006)

PHENIX

data from: Phys. Rev. Lett. 98, 232302 (2007)

Testing Thickness Scaling

thicker via
trigger to
reaction plane
selection

out

mid

in

peripheral

central

thicker via centrality
selection

Cu+Cu

Au+Au

Away-side structure vs. beam species, beam energies, and centrality
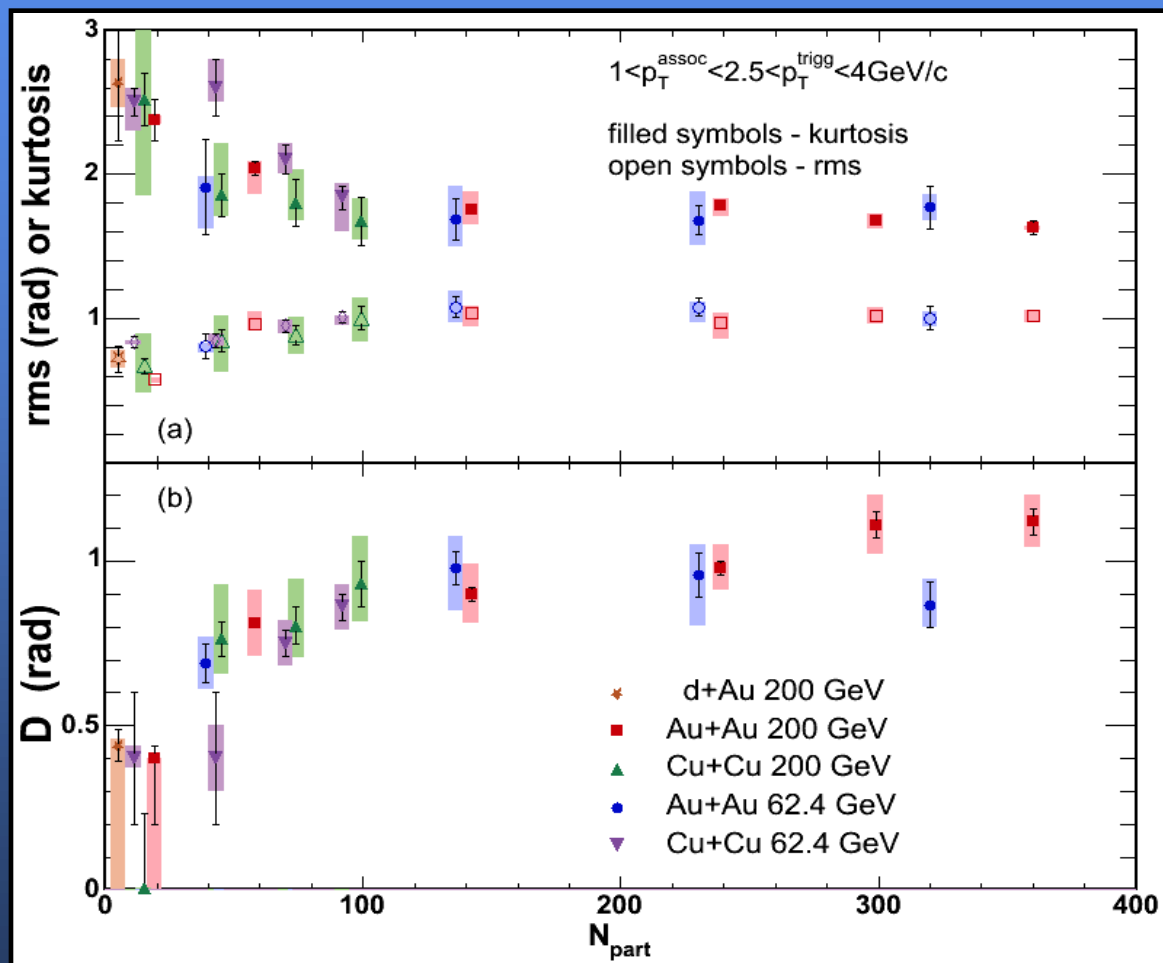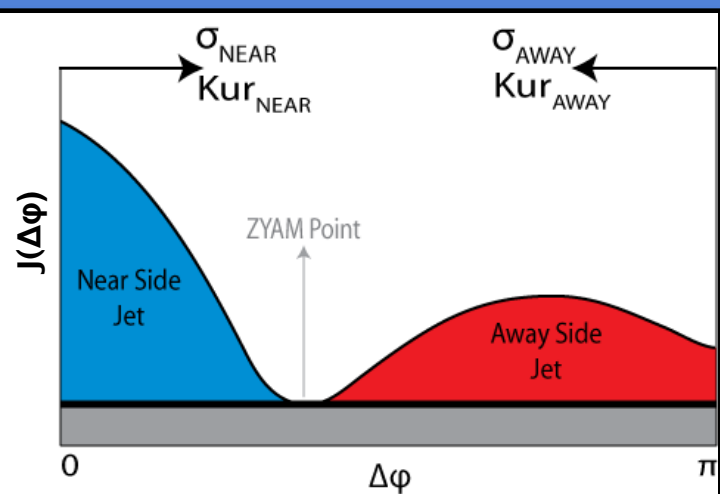
<u>All cases:</u>
  Peripheral similar to p-p

● Central shows development of "lobe"-like structure

N*part* Shape Scaling

nucl-ex/0611019

Shape saturates above 100 N$_{part}$